

GEOMETRICAL RULES

Made Easy for the Use of
MECHANICKS

Concern'd in
BUILDINGS:
CONTAINING,

New and Infallible Methods, for Striking out from proper Centers, the Groyns of Arches regular and irregular, the Angle Brackets of Coves, Crowns of Beaufets circular or elliptick. With many other useful Problems relating to all Curve Lines, introduc'd in Building.

A L S O,

An E S S A Y, on the Nature and Properties of Arches in general, mechanically consider'd with Respect to their Shapes and Duration, exemplified by several Geometrical Figures, demonstrating their Property and Powers, interspersed with some Remarks on the intended Bridge at *Westminster*. With a Proposal for Building the Piers, by a Method practicable, so as to keep out the Water while erecting. The Whole design'd chiefly for the Information and Use of all *Building Artificers*, &c.

By ISAAC GADSDON.

L O N D O N:

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THE P R E F A C E.



I is a common Observation, that every Generation grows Wiser, and I don't know any Thing that is a greater Confirmation, (to this old Saying) then to hear Artificers and Tradesmen (when they meet together) relate their former Methods of Practice in their own Way of Business, and by comparing them with the Present, seem surpriz'd at the Improvements that have been made in their several Arts and Occupations whereunto they belong; From hence it's very plain, that there have been Men in all Ages, whose Ingenuity have led them out of the common Track, to find out nearer and better Methods to accomplish their Designs, than they had ever been taught, or had before practic'd; And was a Man to indulge his Curiosity so far as to examine the several Employments of Life, I believe he would hardly find any that are so Mean and Trifling, but what would admit of a Difference in Practice, for how often may we find Men in trifling Employments, contending for superiority of Judgment, and dispute very

warmly about the different Methods of performing the several Branches of their Occupation. And if there is a Difference in the Practice of mean Employment, there is undoubtedly a great Deal more Difference to be discover'd in the Practice of those Arts and Employments, that are of a more valuable Consideration. The Art of Building alone will be sufficient to justify the Truth of this Observation, for as this Art consists of many Branches, it admits of many Practitioners, and as Mankind differ in their Abilities, it must consequently cause a Difference in their Practice, and if a Man be ingenious, it gives him a great deal of Room to exercise his Fancy; for here, the Field of Art, layeth more often for the Mind to Range in, and is not confin'd to such narrow Conceptions, as are very often found sufficient to carry on a great many Employments of a lower Nature.

Building if consider'd in all it's Branches, is an Art very extensive, and it must be allow'd to have receiv'd great Improvements within those few Years past, but, whether that hath proceeded entirely from the many New Buildings lately erected, or from some other Cause, is not my present Enquiry.

The Theory, or designing Part of Building, hath always been esteem'd preferable to the Practick, and Workmen have (for the
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Generality) valued themselves, and been esteem'd by others, according as they have known more or less of it. For this Reason, one would think, that they would be very ready to embrace any Instruction, relating to the Theory of their Employment, for, I have very often known good Workmen, to be at a Lo's, for want of the Theory to direct them, and commit gross Mistakes, which the Knowledge of Lines would have prevented. For there is nothing that I know of, that can be of greater Service to any Mechanick, than to know the Theory of his Employment; and I have known several ingenious Workmen, belonging to the Building Trade, that by making close Application to the Theory, have become good Surveyors.

And, indeed, they ought to be really so, that undertakes so ingenious an Employment; for it is not for every one that can make a fine Drawing, that is qualified to be a Surveyor, that being (in my Opinion) but the superficial Part, for I can assure the Reader, that the original Designs of the great Inigo Jones, were but poorly Drawn in Comparison to the common Practice now known.

I should not have mention'd those Drawings, had it not been to shew that there may be good Surveyors, without being fine Draughts-men, and the daily Practice of

some of our Moderns, plainly shew that there are fine Draughtsmen, that are not good Surveyors.

By what I have here said in Respect to Drawing, I do not mean to discourage any Person, from endeavouring to excel in that ingenious Art, nor to encourage any one to sloven over a Design, but what I would observe, is only that there is a great deal of Difference between the Drawing and the knowing of Lines, in Respect to Building; for as the Knowledge of Lines, is the Base of the Mathematicks, it must consequently be that of Architecture, and without them it would be impossible for one Man to convey his Ideas to another, in Respect to a Building; therefore, this the Architect ought to study well, and not only Lines, but Things themselves, that he may be a Judge of the Materials required in a Building, and know (the better) how to apply them to their proper Use. In short his Knowledge ought to be very Extensive, his Fancy fruitful, his Judgment sound, and be nicely just in all his Proportions, in Respect to Distance as well as Magnitude, that there may be a Symetry preserved in all the Parts, both Internal and External; and if the Design be well adapted to the Situation, this Symetry will extend itself further, and bear some Analogy to the Landskip it stands on.

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This appears to me to be a very necessary Branch of Architecture, and I believe it is not always consider'd in designing of a Building, or at least is very seldom put in Execution, but whether it may be thought too nice for Observation, or whether it be not as yet rightly understood, I will not pretend to determine; but, however that be, I believe, it may (in many Situations) be introduc'd to a very good Effect, for it's a very common Observation, amongst those Persons that have a Taste of Gaiety and Dress, that Garments made of different Colours, and in different Shapes, will have a different Effect on the same Person that weareth them; So the Face of Nature, will undoubtedly bear the same additional Improvement, if the Completion and Features are rightly understood, and the Ornaments in a Building, are well adapted thereto by the Designer.

I shall forbear further Remarks, because this hath already been observ'd in some Lectures on ARCHITECTURE and Harmonick Proportions lately publish'd, in which, that Author by infallible RULES, and the Strength of a fine Imagination, hath carried this Observation to a greater Length than any Writer on this Subject, and hath there shew'd in a very delicate as well as Poetical Manner, what Orders of Architecture are most proper
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to be apply'd to particular SITUATIONS, which, if rightly chosen, will preserve that Symetry I have been speaking of, and constitute a Kind of Harmony which will always be the Result of Proportion and Regularity.

From what hath been said on this Subject of Building, I think it appears very plain that it must require a great deal of Judgment, to delineate a good Design, and it is as evidently plain as much Ingenuity is required in the Artificers, to perform the same in a Workman-like Manner, for altho' it be not absolutely necessary for all Workmen to have designing Heads, yet they ought to have conceiving Ones, that they may readily discover the true Meaning of the Architect, by forming to themselves a good Idea, not only of the Whole of what they are to perform, but of the Parts also; that they may take the nearest and best Methods to work the same, and put them together in a Workman-like Manner.

This I must own in many Cases of Building, is very easy to conceive, and in a great many others very difficult, therefore, I would advise the Reader, (if he hath not already) to study the Nature of Lines, by learning a little Geometry, and by observing what Instructions he will find contain'd in this Book, he may soon be able to perform his Work in any irregular

lar Form or Shape that is requisite or practicable to be perform'd in any Building whatsoever.

But, for the Sake of those that are unacquainted with the Nature of Lines, I have begun this Undertaking with defining the Properties of those Geometrical Figures, that have any Relation to the ensuing Problems. To the End, that the Practitioner may comprehend the Theory or Hypothesis in Building, and see the Reason of what he is about to perform, which I flatter myself will answer his Expectation, whenever he hath an Occasion to make Use of them.

But before I proceed to give any further Account of my own Performance, I must beg Leave to take Notice of the Performance of others that have wrote (before me) on the same Subject, which are only two that I know of, and they are Mr. Halfpenny and Mr. Hoare.

Mr. Halfpenny in his *Art of sound Building*, hath publish'd a Method to strike out the Groins of Arches, the Angle-Brackets of Coves, and several other Things of the like Nature, and hath call'd it a Geometrical Method; how far the Contents will agree with the strict Rules of Geometry, I shall leave those learned Readers to judge, that have seen the Book; but for those that have not, are to observe that his Method chiefly consists in tracing of Lines, either by Way of Intersection,
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or by drawing them Parrelel from one Line to another, but the Result of both Ways was this; that you are to prick in Nails at certain Points, (determin'd by proper Direction) and bend a Lath round the same, and with a Pencil strike the Arch or Curve according as the Nails and Lath directs, and that will be the Groin or Angle-Bracket required. Such a Line, (I must own) will be like the Groin or Bracket sought, but then the Trouble and Time that is required to get at it, is what put me on thinking on some better Method, that might be sooner perform'd, and to a better Effect.

Mr. Hoare was the next that had any thing to say to the Publick on this Subject, and by a long and specious Advertisement in a News-Paper, I was prevail'd on to purchase his Book, not knowing but that he might have taken the same Method I intended to take myself. But perusing his Performance, I found he had followed the same Track that Mr. Halfpenny had mark'd out before him, and had perform'd very little, except reducing Mr. Halfpenny's Folio into a small Quarto, and by that Means rendered his own Performance a fit Companion for the Pocket, both in Respect to the Size as well as Price.

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This I must own was a Disappointment for I had waited several Years in Expectation of seeing most of Mr. Halfpenny's Designs new Modell'd, believing some one or other would have discover'd a better Method, and have given it to the Publick in a much better Manner.

How far I have exceeded in that Respect, I must now leave to the Judgment of the Practitioner, who undoubtedly must know whether it is not a nearer and a better Method to strike an Arch or Curve from a Center, than it is to trace them out by Lines, and after all that Trouble, be obliged to prick in a Parcel of Nails, and prepare a Lath fit for that Purpose, before you can strike out the Line you want.

Surely there doth not want any deep Penetration to determine this Affair, for as most of the ensuing Problems have their Foundations in Geometry, they will bear a Demonstration; therefore, it will be no difficult Matter to discover which of the two Methods are most Practicable.

I am not insensible that some of the Problems will appear mean and trifling to such who have no Occasion for such Instruction, (and it's very likely) will think I have been too Particular, but if they will please to consider that this is intended for general Use, and if they have no Occasion for such low
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Instruction, there are several others that may who are not so expert in their Business as they, besides, it is the common Way of most Authors that pretend to instruct in any Art or Science, to begin with the first Rudiments of that Art, and by gradual Steps advance to those Rules that are more difficult, and this Method I have endeavour'd to follow as near as the Subject will admit.

I must own, that I have omitted several Problems, that are to be met with in the Works of Mr. Halfpenny or Mr. Hoare, which I think have little or no Relation with our present Methods of Building, but instead thereof, I have substituted others in their Room, which I conceive to be more useful, but to make the Reader amends; I have bestow'd several Pages on the Nature and Property of Arches, in Respect to their Shape and Duration, which Subject, naturally led me to make some Remarks and Observations on the intended Bridge at Westminster, and likewise on what hath been publish'd on that Subject; And if what I have said there or in any other Part of this Work, should be of any Service to Mankind, so far as to give them any useful Hints, whereby the Theory of Building may be improv'd, I shall not think my Leisure Hours lost or any Ways misemploy'd.

J. GADSDON.



DEFINITIONS.



AN Angle is an Indefinite Space terminated by the Meeting of two Lines which intersect or touch each other on a Plane, and may be either right-lined, curved or mixt.

A right-lined Angle is that which is made by the Interfection or Meeting of two right Lines, as *A*, the Point at *a*, being the Point of the Angle.

A curved Angle is that which is made by the Meeting of two Curves, or crooked Lines, as, *b*.

B

A

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A Mixt is made by the Intersection of a right Line and a crooked or curve, as *c*.

Angles whether plain or spherical may be either right, acute, or obtuse.

A right Angle is when one Line falls perpendicular on another, as *d*; it consists of 90 Degrees or one Quarter of a Circle, a Circle being commonly divided into 360 equal Parts called Degrees.

An acute Angle is any Angle that is less than a right one, as *E*, or that consists of less than 90 Degrees.

An obtuse Angle is greater than a right one, or that consists of more than 90 Degrees, as *F*; supposing the dotted Line in each Figure to represent the intended right Angle.

A Triangle is a Figure that hath three Sides and three Angles, as *G*.

Any three whereof being given (except the three Angles) the other three may be found.

In any Triangle the three Angles taken together are equal to two right ones. Wherefore having any two given, the third is known of Course by subtracting the Sum of the given ones from 180 Degrees.

In a right-angled Triangle where one Angle is a right one, the other two are necessarily acute. And both together are equal to 90 Degrees,

Degrees, wherefore one is always the Complement of the other to a Quadrant.

A Segment of a Circle, is a Part of a Circle terminated by a right Line less than the Diameter, and by a Part of the Circumference, as A.

C H A P. I.

On the CIRCLE, &c. with their Properties.

First, **A** Circle is a plain Figure contain'd under one Line, as the Line AAA in *Fig. 1.* which Line is called the Circumference, or Periphery, and all straight (or right) Lines passing through the Center *a*, and touching each Side of the Circle are call'd Diameters, as the Line B, the Half of which is called the Radius, or Semidiameter.

Half a Circle is called a Semicircle. All straight Lines, as C, not passing through the Center of a Circle are called Chord Lines, and the Parts so cut off are called Arches or Segments of a Circle.

Secondly, An Ellipsis, or Oval, is a Figure contained under one Line, and differeth from a Circle according to the Difference of its Di-

meters, as in *Fig. 2.* the shortest Diameter B is called the Conjugate; the longest C is called the Transverse.

These Figures have several Properties, which I might enlarge upon, but as they will be of no Use in the following Sheets I omit them.

Thirdly, A Cylinder is a solid Body, round and long, whose Sides are parallel, or at equal Distance one from another, as in *Fig. 3.* the Ends being square (or at right Angles) with the Sides must consequently be a Circle, as A. But if they are cut obliquely, they become Ellipsis's, as the Section D, and according to what *Obliquity* the Ends are cut the *transverse* Diameter will increase, but the Conjugate will always remain the same.

Fourthly, A Cone is a solid Body, round and wide at the Bottom, or Base, and diminisheth to a Point at the Top resembling a Sugar Loaf; see *Fig. 4.* It hath the same Properties that the Cylinder hath, in Respect to the Ellipsis and Circle; for if it be cut at right Angles to the Axis, or Middle Line A, that Section will form a Circle, but if cut obliquely, (as the Section B,) 'twill form an Ellipsis; but as the Ellipsis cut from a Cylinder can be enlarg'd

larg'd but one Way, those cut from a Cone may be enlarg'd both Ways, but not in the same Proportion. A Line made perpendicular thro' the Center is call'd the *Axis* of the Cone, and if the Top of it be cut off; the Part remaining is called the *Frustrum* of a Cone.

This Body admits of many more Sections and Properties, which would be of no Use to define here, and for that Reason are omitted; but as to these I have mentioned, I must desire the Reader to take Notice of them; the Cylinder especial'y. And if he doth not conceive the Sections by the Figures it will be best to make the Bodies themselves of Wood or other soft Matter, and cut them according to Direction, and he will soon discover that a Cylinder cut obliquely will be an Ellipsis; and as all semicircular Arches are Half-cylinders, their Groins, or Miters, must consequently be Half-Ellipsis's. But of this more hereafter.

C H A P. II.

Some Introductory Problems.

P R O B L E M I.

On a right Line given as A, to raise a Perpendicular. Fig. 5.

O P E N your Compasses to the Length of the whole Line, fix one Point at *a*, and extend the other Point to *e*, and make a Scratch; then fix your Point in *c*, and make another Scratch at *e*, then take Half that Distance you have in your Compasses, and set it off on the given Line at *A*; and a Line drawn from the Point *A*, to the Point *e*, where the two Scratches intersect will be perpendicular to the given Line *a, c*.

P R O B L E M II.

To raise a Perpendicular at the End of a Line given as A. Fig. 6.

Proceed as if you were to raise a Perpendicular from the Middle of the given Line, then draw

draw the Line B, through the Intersection of the Scratches C at Pleasure, then set off the same Distance you have in your Compasses upwards from C, on the Line B, and from thence draw a Line to the End of the given Line A, at *d* to *e*, which will be at right Angles, (or perpendicular) to the Line A.

P R O B L E M III.

Any Part of a Circle being given to find the Center be it more or less than a Semicircle. Fig. 7.

Let ABC be the Segment (or Part of a Circle) given; draw the Chord Line AC, then raise a Perpendicular from the Middle E of the Line AC, at Pleasure, then draw the Chord Line AB, and from the Middle D, of that Line, raise another Perpendicular and the Point F, where that intersects the other Perpendicular, will be the Center required.

P R O B L E M IV.

A Line being given, divided into any Number of Parts; to divide another given Line in the same Proportion, as Fig. 8.

Suppose the Line A, divided into equal or unequal Parts, as, *a b c d e f g*, and the Line B be

be required to be divided in the same Proportion; make A the Base, and B the Hypotenuse of a Triangle, draw the Line which compleats the Triangle, draw Lines from all the Divisions, *a b c*, &c. parallel to that Line, and they will divide the Line B, in the same Proportion.

This is a very useful Problem, and may be serviceable to Workmen on several Occasions; for if a Man hath any Moulding (that consisteth of many Members) ready drawn out, and wanteth another of the same Sort, either larger or less, this Method will give it him sooner than to divide it anew; nay should he want to lengthen or shorten any one Order, with its proper Pedestal and Entablature (if he hath Room to lay down the Lines) he may perform it by this Method. And if he hath not Room, it may be done in Parts, observing to set off each Line, or Part, in the same Angle.

Mr. *Halfpenny* and Mr. *Hoare* have been so fond of this Problem, as to make it the Basis of most of their Schemes, and have carried it through all their Designs relating to Curves, in order to find out the Groynes of Arches; the Angle Bracket of Coves, and several other Designs of the like Nature. But I hope the Reader will find in the following Sheets a much better

better Method ; a Method that will not require a great many Lines, no Nails, nor bended Laths to strike the Curve ; but performs it by Centers ; this I shall endeavour to make easy and familiar to the Practitioner by giving the Theory as I go on, and describing such Instruments as are proper to perform it, and as the Trammel is the best and usefulest Instrument, I must desire those Readers that are unacquainted with it to observe the following Description.

A Trammel is form'd of two Pieces of Wood crossing each other at right Angles in the Middle ; (as in Fig. 9.) with a Groove plow'd in the Middle ; and when fitted together the Grooves must be cut, one into the other ; the Length you must proportion according to your Design, and brace them as you see in the Figure. Then prepare a Rod with two moving Centers, or wooden Pins, and fit them to the Grooves, so as they may slide up and down at Pleasure ; then use it in the following Manner.

Note, As Joyners and Carpenters very seldom want above half an Ellipsis in their Way of working the upper Part will be useless, and one in the Form of a T will do as well.

PROBLEM V.

To strike out an Ellipsis with a Trammel to any given Proportion. Fig. 10.

Suppose you would have one, 6 Feet by 4, take half your longest Diameter (which is 3 Feet) and set off from the Tooth or Pencil at the End of the Rod to make the Mark; and there fix one Center; then take Half the shortest Diameter and set off as before, and there fix the other Center, then apply the Rod to the Trammel by putting Centers or wooden Pins into the Groves and move the Rod quite round the Periphery A, B, C, D keeping the Centers in the Groves, and that will describe the Ellipsis required.

PROBLEM VI.

To strike out an Ellipsis with a Pair of Compasses to any given Proportion. Fig. 11.

Take the Difference between the two Diameters, and divide into 3 equal Parts, take two of them, and set off on each Side the Center on transverse Diameter, as B and E, take the whole Distance between B and E in your Compasses, and fix one Point in either B or E,

extend

extend the other to the Conjugate Diameter, and where that Point falls on that Line as at D and F ; from those Points draw Lines at Pleasure as you see in the Figure ; then from B as a Center strike the Arch A, and from E, the other Arch A ; then from the Center F, strike the Arch *ac b* ; and from the Center D, the Arch *d G f*, and all those Arches will meet where those straight Lines intersect and form an Ellipsis.

This Ellipsis will be as true a one as can be drawn with a Pair of Compasses, and fit for any Use ; but if considered in a mathematical Way, it cannot have the true Properties of an Ellipsis, because their Centers are always moving, whereas those being fix'd can only strike such Curves as will co-incide, and appear very much like a true one. Besides this Sort of Ellipsis may be drawn parallel, which the true ones cannot, because they flow from a right Line and want to get into a Circle, as may be be easily prov'd by first drawing one, whose Conjugate Diameter shall not exceed an Inch, and the Transverse not be less than two Feet : I say, if you endeavour to draw other Ellipsis's parallel to such an Ellipsis, by increasing both the Diameters alike, and draw a great Number you will have one at last very near a Circle ;
and

and may be discover'd by measuring between the Diameters of the first and the last that they are not parallel, and if those two are not 'tis impossible any other two should.

PROBLEM VII.

To strike out an Ellipsis with a String. Fig. 12.

This Method is most commonly made use of, and performs the same as a Trammel, if the String would not stretch, but as all Lines are of a stretching Nature, it cannot be used with that Certainty that in many Cases is required, but may be made use of in a great many others, observing the following Method.

Take Half the Conjugate Diameter in your Compasses, and set one Point at the Center and the other at either End of the Transverse, extend the other, and where that falls stick your Nails as at A and B, for the Center's; then take a String, or Line, the least apt to stretch you can get, put it round the Nails and tie it to such a Length that your Pencil C may just reach the End of one of your Diameters; then keeping the String equally tight, let it work round the Nails, and your Pencil will strike this Ellipsis.

Note,

Note, There is another Method that may be made use of to strike the Quarter of an Ellipsis ; which is to fix a straight Piece of Wood across a Drawing-Board, at right Angles with the Side, then take a Rod half the Length of the Transverse Diameter, and from the Pencil End set off Half the Conjugate Diameter on the lower Side of the Rod, and there stick in a Nail, or Pin, to work along the Edge of the Drawing-Board ; the End next the Pin make round to work against the Edge of the Piece nail'd on the Board, and that will perform the same as a Trammel, as far as it will go.

The Definitions and Problems hitherto laid down are only introductory to what will follow, the Theory whereof depends upon them ; which Definitions and Problems, if the Reader will but give himself a little Time and Application to understand, the following Propositions will be more easily perform'd and better understood.

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C H A P. III.

P R O B L E M I.

To find the Groin Arch of two Semicircular Arches that intersect or cross each other at right Angles. Fig. 13.

THE Theory of this Problem depends on a Cylinder, which being cut obliquely will be an Ellipsis, and as all semicircular Arches are the Half of Cylinders, the Groins, or Mitters, of such Arches must consequently be Half-Ellipsis's, and may be found by the following Method.

Suppose the Arch A, to rise three Feet and Spand fix, or any other given Proportion ; let fall the Perpendicular B at one End of the Diameter C, and equal to it, which will be two Sides of a Square ; then draw the Diagonal Line D, and that will be the Transverse Diameter, and the Line CA will be the Conjugate, which set at right Angles in the Middle of the Tranverse D, as the Line E, then take a Trammel, or String, and strike the Ellipsis F, F, F, the Half of which will be the Groin sought.

P R O -

P R O B L E M II.

To find the Groin Arch of two semicircular Arches, that intersect one another obliquely, as in Fig. 14. Plate 2.

Suppose them of the same Dimension as the last, or any other, you must draw the Plan of their Intersection as you see in the Figure, then draw the Diagonals, A and B, and they will be the Tranverse Diameters, the Conjugates will always continue the same; then proceed as directed in *Prob. I*, and this Method will find out the Groin be the Angle of Intersection what it will.

P R O B L E M III.

To find the Groin Arch of two Elliptical Arches, whose Transverse Diameters are horizontal or level, and intersect at right Angles. Fig. 15.

Suppose it were required to find the Groin of the Elliptical Arch E, you must proceed as in *Prob. I*. to square the horizontal transverse Diameter A, and take the Diagonal Line B for your Transverse Diameter of the Groin and the dotted Line C will be the Conjugate; proceed as before directed, and the Half of the Ellip-

fis K, K, K will be the Groins ought ; and if the Arches cross obliquely you must proceed as directed in *Prob. II.*

P R O B L E M I V .

To find the Groin Arch of two Elliptical Arches, whose Conjugate Diameter is horizontal, and intersects at right Angles. Fig. 16.

In this you must proceed, as in the former, by squaring the horizontal Line A, (which in this Arch is the Conjugate Diameter) and take the Diagonal Line C, for a new Diameter, but whether it will be a Conjugate, or a Transverse, the Diameters of your first Ellipsis will determine ; for, if they are in the same Proportion, as the Side of the Square is to its Diagonal, the Groin Arch will be a Semicircle, but let the Proportion be what you please, if you take the dotted Line D, and the Line C, for the Diameters of the Ellipsis that is to form the Groin, they will tell you which will be the Conjugate, and which the Transverse ; but let that happen as it will, the Line C must always be the horizontal Diameter, and the Half-Ellipsis, or Circle, on either Side that Line will be the Groin sought.

PROBLEM V.

To find the Groin Arch of a semicircular Arch meeting with one that is Elliptical at right Angles, as in Fig. 17.

Notwithstanding these Arches differ their Groins will be both alike, and may be found by drawing the Plan of their Intersection, and taking the Diagonal for the Transverse Diameter, and the dotted Line A for the Conjugate, strike the Ellipsis B, B, B, the Half of which will be the Groin sought.

Note, All Arches that are of different Spand, and are to intersect each other, one of them must be elliptical, otherwise they will not rise to the same Height and coincide one with the other ; and if they are both elliptical and differ in Diameters, the Method is exactly the same.

PROBLEM VI.

To find the Groin Brackets, where a small Arch is cut out of a larger, and both are Semicircles. Fig. 18.

When these small Arches are cut off of large ones, it is commonly introduce a Window or

Door, and the Groin Brackets may be found by the following Method ; draw the Plan of the great Arch A, then draw the little Arch B on the Side, as you see in the Figure ; and from the Ends D D, of the Arch B, draw the Lines K and L, through the Middle Point, c, and either of them will be the Transverse Diameter of the Ellipsis, o o o, and the Conjugate will be the Diameter of the great Arch A, and the two Groin Brackets will be the Arches R T, which are cut off by the Line L ; these you must place exactly over their respective Diagonals L and K, and let the two flattest Ends meet together and stand uppermost, then will the little Arch B meet and coincide with the great Arch A, and be the Quadrant O, D, T, D.

I could give several other Problems of this Nature, but I believe the Reader by this Time is so well acquainted with my Method of Proceeding, that to give any more would look like an Affront offer'd to his Understanding ; for if he hath discover'd the Theory of what I have hitherto advanced on this Subject, there can be no Arches that are compos'd of the Ellipsis, or Circle, but he may find out the Groin thereof, let them meet or cross each other how they will.

P R O B L E M VII.

To find the Angle or Corner Bracket of a Cove that 's Part of a Circle, as Fig. 19.

As all Coves are Parts of Arches, so all Angle Brackets must be Parts of their corresponding Groins; for Example, Suppose it was required to find the Angle for the Cove A, you must proceed (as in *Prob. I.*) as if you were to find the Groin of the whole Arch, and strike the same Ellipsis, B B, and place it as you see in the Figure; then continue the Line C, (which limits the Progression of the Cove) till it meets with the Transverse Diameter of the elliptical Arch B B, and from thence raise the perpendicular Line D, and that will cut off just as much as will make the Angle Bracket B of the Cove A.

But if the Room be not square, or the Sides not at right Angles one to the other, and it is not a great deal out of Square; you must draw the Plan of the Projection of the Cove according to the Angle of the Room, as the Figure B, and set off the Line A, from one End of the Ellipsis on the Transverse Diameter, and from thence raise a Perpendicular, and that will cut off the Part required for your Angle Bracket,

Fig.

Fig. 20. And if it be very much out of Square you must draw the Plan of the whole Room, as the Figure 21, and set off the Diameter of the Circle that forms your Cove and draw Lines parallel to the Sides, as you see in the Figure, and take the Lines B and D for the Transverse Diameters, and the Conjugate Diameters will be the Diameters of the Circle that form'd the Cove; then proceed as before directed.

N. B. This Method will do for Hexagons, Heptagons, or any right-lined Figure whatsoever.

P R O B L E M VIII.

To find the Angle Bracket of an Elliptical Cove, Fig. 22; whose transverse Diameter is horizontal as the Cove, B.

Square the horizontal Diameter of the Ellipsis that forms the Cove, and proceed as in *Prob. VII* to strike out the Ellipsis, C D, then continue the Line E, till it meets with the Transverse Diameter of the Ellipsis C D, and from thence raise a Perpendicular K, and that will cut off the Arch C, which will be the Angle Bracket required.

PROBLEM IX.

To find the Angle Bracket of an Elliptical Cove, whose Conjugate Diameter is horizontal as the Cove. Fig. 23.

Square the Horizontal Diameter of the Ellipsis that forms the Cove K, and proceed as before taught, to strike the Ellipsis R, T, then continue the Line O, till it meets with the Line D, and from thence raise the Perpendicular L, and that will cut off the Arch R, which will be the Angle Bracket required.

But here it is to be observ'd, that as in the foregoing Problem, the new Ellipsis that form'd the Angle Bracket became longer, here it may become shorter, for if the Diameter of the first Ellipsis be in the same Proportion as the Diagonal is to the Side of a Square, the Angle Bracket may be Part of a Circle; and if the first Ellipsis be a long one; the Diagonal Line D, will become the Conjugate Diameter of the new Ellipsis that is to form the Angle Bracket, by making the dotted Line E to form the Rise of the two Diameters F and F to be equal.

N. B. I have thought proper to shorten the Directions of some of the Problems concerning Coves, because the Method is exactly the same,
and

and may be applied to any Cove that is Part of any Ellipsis, or Circle, take it out of what Part you please, for the Line of Projection being continued until it meet with the Diameter D, and from thence a Perpendicular being raised, it will cut the corresponding Part required, as you see in the above Figure, the Rise being always consider'd equal in both, and is made by a Line parallel to the Conjugate Diameter D.

CHAP. IV.

PROBLEM I.

To glew up the Crown of a Buffet, whose Front and Back are both Semicircles. Fig. 24.

THIS Sort are in most common Use, and are the easiest to be conceiv'd; they are perform'd by the following Method. Take a thin Piece of Board for your Mold, which must be just Half the Semicircle, as the vacant Space D, in the Figure; divide this according to the Thickness of your Stuff, as you see in the Figure, and let the Joints cross each other in the Plan; then take the Line, *a*, for your first

first Center, the Line, *b*, for your second, and so on till you have compleated the whole Crown, observing to set a Bevel to every Thickness, according as you find them on the Compass Edge of the Mould, and work the Pieces by the same, then glew them down one upon another, and that will form the Crown required.

To glew up the same in a different Manner proceed as before directed, and glew up three or four Rounds (as will suit your Design best) then take them off your Board and glew up the same Quantity, and so on till you have got enough for the whole Crown, then glew together in Parts. This Method is most proper when the Crown is not to be painted.

PROBLEM II.

To glew up the Crown of a Buffet, whose Front and Back are both Elliptical. Fig. 25.

To perform this you must have two Moulds one must be the Quarter of the Ellipsis *B*, the other a Quadrant, or Half a Semicircle, as the Space *A*, these you must divide according to the Thickness of your Stuff, then will the Lines on the Quadrant be Half the Conjugate Diameter, and the Lines on the Elliptical Mold will
form

be half the the Tranſverſe Diameter of all the Elliptical Pieces that form the Crown ; that is the Line O, will be one Center, the Line, *a*, the other of the firſt Piece you glew on ; and the next Lines, *viz.* *b*, *c*, will be the Centers of the neat Pieces, and ſo on : And the Quadrant Mould will give you thoſe at the Ends ; then proceed as directed, *Prob: I.*

P R O B L E M I I I .

To glew up the Crown of a Buſſet, whoſe Front is a Semicircle and the Back elliptical.
Fig. 26.

This Sort of Buſſet is very often introduc'd where the Receſs that is to receive it is ſhallow, and not half ſo deep as it is wide.

The Method of performing it differs very little in Practice from the laſt, and the Difference is in the elliptical Mould, which in the former is on the Conjugate Diameter, and here you muſt divide on the Tranſverſe, as you ſee the Space G, is in the Figure ; then begin with the Lines O, and A for the two firſt Centers, and proceed as before directed.

PROBLEM IV.

To strike out the Ribs of the Crown of a Buffet that is to be plaister'd, and is a Semi-circle both Ways. Fig. 27.

This Sort of Buffets are often plain, but when they are very large, and will admit of being enrich'd with Fruit, Flowers, a Shell, or other Ornament, according to the Fancy of the Designer. First, Strike out the Back Plate, and divide it into the Number of Ribs you design for the Crown, as the Figure D, and from the same Centers strike out the Ribs which will be Quarters of Circles, and fix one End to the Back-Plate, and the other Ends must meet altogether in the Center of the Crown, and they will form the Crown required.

PROBLEM V.

To strike out the Ribs of the Crown of a Buffet that is plaister'd, whose Front and Back are both elliptical. Fig. 28.

First, Strike out the Back and Front, according to your Dimensions, as before directed, and divide the Back into the Number of Ribs you design for the Crown, and from thence

D

draw

draw Lines to the Center, as you see in the Figure B, then take the Line O for one Center, and the Line *a* for the other, and strike the Semi-Ellipsis C, and that cut into two at Z, (Fig. 29.) will be the two first Ribs next to the Front, then take the Line *b*, for the next longest Center to work with the Line O, (which being a fix'd Center to them all, must remain the same) and they will strike the next two Ribs, and in like Manner proceed till you come to the Middle, O, which will be a Center of itself for the Middle Rib, then fix them in their proper Places, observing to let the Ends which are cut in funder, meet altogether in the Center of the Crown, and fix the other Ends to the Back Plate to follow one another as they were struck out.

PROBLEM VI.

To strike out the Ribs of a Buffet that is to be plaister'd, whose Back is elliptical and Front a Semicircle. Fig. 30.

The Method of performing this is nearly the same as the last, (*viz.*) first draw the Back and Front, then divide the Back according to the Crown; and from thence draw Lines to the Center, as you see in the Figure, then proceed
as

as directed in the former Problem, *viz.* to take the whole Line O, for one Center, and the Line *a*, for the other, which will be a little shorter, and therefore will produce a Semi-Ellipsis nearly a Semicircle, which being cut in two will be two first Ribs next to the Front, then take the Line *b*, for the next Center to work with the Line O, which is the fix'd Center to them all) and that will strike the next two Ribs, and so proceed on till you have compleated the whole Number, then fix them in their proper Places only observing that as in the last Problem the Ends where they cut in two went to the Crown, here they must be fix'd in the Back Plate, and they will form the Crown required.

PROB. VII.

To frame the Crown of a Buffet that is a Semicircle both ways. Fig. 31.

This Sort of Buffet is not very common, there being a great deal of Care and Trouble required to work them clean; by Reason the Mouldings must be struck by Hand and most of the Plowing will be against the Grain; but those that have a Mind to work one after this Manner may observe the following Method.

First, Glew up the framing (as directed in *Prob. I.*) until you have enough for the Front Stile O, and likewise for the Spandrel Rails, *a, a, a, a*, which must diminish, as you see in the Figure, and be mortised into the Compass Place *e*, which must be worked by a Mould struck from the Center as your Framing, and must be mortised into the lower Rails, *a, a*, whose lower Edge must be rebatted to receive the Back, then set off from your first Center, the Thickness of the Moulding you stick on the Framing, and that will strike the Mould to work the Pannels by ; which must be glew'd up by the same, so that the Joints may lie horizontal, or level as the Pannel D, in the Figure ; for were you to make a Pannel never so thin, and think to bend it, you will be deceiv'd, for that will not form a regular Curve both Ways ; therefore it is much the better Way to glew them up, as before directed.

PROBLEM VIII.

To Vinear the Crown of a Buffet in Goars that is a Semicircle both Ways. Fig. 32.

A Buffet finish'd after this Mannèr is also very uncommon, for I do not remember to have seen above two, and they are both in
Hampton

Hampton Court Chapple ; and (in my Opinion) have a very good Effect. And as it is natural to most Mechanicks, when they see any Thing uncommon perform'd in their own Way of Business, to have some Thought about the Method that was taken to perform it ; therefore this Consideration prevail'd with me so far as to recommend the following Method to perform the same.

Suppose the Semicircle *D*, to be the Back of a Buffet, you must divide it according to the Number of Goars you design, then draw the Line *a*, equal to the Semicircle *D*, and set off Half the Breadth of your Goar on each Side the middle Point *c*, and from thence raise a Perpendicular at Pleasure as the Line *z* ; then from the Half-Breadth of your Goar, *viz.* from the Point *a*, draw a Line to either End of the Line *a*, as the Line *o*, and from the Middle thereof raise a Perpendicular, as the Line *x*, and where that meets with the other Perpendicular *z*, will be the Center to strike the Curve Line *n, n*, which will be one Side of the Goar ; then perform the same on the other Side as *m, m*, for the other Side of the Goar ; which being cut in two at *c*, will make two Vinears in the Shape required. And by the same Method you may strike out all the rest : then glew them

down with the broad Ends towards the Back, and the piked Ends will all unite in the Center of the Crown.

N. B. This Method is very likely to do if the Goars are narrow, and the Vinears very thin, but if they exceed two Inches and a Half or three Inches at the Bottom, the safest Way will be to let the Vinears be thick enough to be work'd by a Mold (broadways) on the Back-side, and bend them longways only, and work the Inside (after it is glew'd down.) And I am apt to believe that those at *Hampton Court* were work'd after this Manner; for their Vinears seem'd to me to be six Inches at the Bottom, and for that Reason (I think) it impossible to be laid in a thin Vinear because the Middle Line *a*, must become as long as the Curve Line *n, n*, otherwise it will not stick in the Middle. But let the Vinear's be broad or narrow, the Method I have here given will strike out the Compass Line for the Edge. But when the Vinears are very narrow, the Difference between the middle freight Line, and the Compass-Line on the Edge is so very little, it is possible that when the hot Glew comes upon it, it may stretch a little, and by that Means lie fast.

As to the Directions I have given in this Problem, or any other that regards the working Part only, I must desire the Practitioner to observe them as such as I should make use of myself; and not as positive or absolute; for as several Men have different Ways of working the same Thing, it is probable they may find out better, but as the Theory is built on Demonstration they may be safely relied on by those that have Occasion to make use of them.

PROBLEM IX.

To strike out a Compass Soffite that is horizontal at the Crown, and splays at both Ends according to the Shutters. Fig. 33.

First, Find the Center that struck out the Head of the Arch by *Prob. iii. Chap. II.* then set off the Margin you intend to shew, and strike the Edge of the Stile next to the Window-Frame; suppose the Arch D, all the other three will be elliptical, and may be found by the following Method.

First, draw the Plan of the Soffite, as if it were to be a flat one, as you see in the Figure, *viz. a*, represents the Back Stile, and *e* the Front; then set off the Splay and draw the Line O', and where that cuts the Stile Line,

let

let fall a perpendicular Line to the Line, *b*, and they will give the Splay of the Stiles, and likewise the Pannell. Then take a Trammel and fix directly over the first Center, as you see in the Figure; then take the Rod that belongs to the Trammel, and fix the Pin next the Tooth or Pencil, to the first Center, *E*, and put in the upper Grove of the Trammel; then bring the Tooth or Pencil to the first Splay, *n*, and observing where the Rod crosses the lower Grove of the Trammel, there fix the other Pin of the Rod, then will the Trammel be fix'd to strike the first Splay *n*, and by the same Method strike out all the other Splays. But if the Soffite be very flat Parts of a Circle will do instead of Elliptical Parts, and the Centers thereof may be found by *Prob. iii.*
Chap. II.

N. B. As there are several Ways of Glewing up those Sorts of Soffites, I have omitted giving any Directions here, and must refer the Reader (if he doth not know of any better) to those I have already given in several of the foregoing Problems relating to Compass Work.

P R O B L E M X.

To find the Return of the Cornice of a Pediment.
Fig. 34.

Draw out the Cornice according to the Angle of the Pediment, then raise a Perpendicular any where so as to intersect the Cornice, as the Line O, *Fig. 1.* and from that Line set off the Projection of the Cornice on a Level, and draw out the Members as you see in the Fig. F and that will be the Return. But if your level Cornice be first given, and you want to find the Pediment or raking Part, draw out the level Cornice F, *Fig. 1.* and raise a perpendicular Line, as O, and from thence set off the Projection and return it as you see in the Figure; then draw the Lines of the Pediment Cornice, G, L, H, M, &c. according to the Angle of Intersection; and from a Line at right Angles give it's proper Return, as L; and that will be the Cornice required, and the Ogee which returns round the Modillion H. There are several other Cases where Moldings require to be enlarg'd to make them a Quadier, that is to make all the Members meet, for if a Semicircle Molding meet with a streight one, as the *Fig. 35.* and the Joint be a true Miter, at 3 the Compass Part will be

be larger than the streight one. But if the Compass Part be the same Breadth as the streight one, and the Members in the same Proportion, then will the Intersection form a crooked Joint, as *Fig. 4*; therefore in such Cases, as I have here describ'd (if it is not to be a true Miter) I conceive the best Method is first to draw the Out-lines of both the Moldings of the same Width as in *Fig. 5*; and from their Intersection draw the Miter-line O, then draw the Members of the streight Parts, and from where they intersect the Miter-line O, draw the Members of the Compass Part, and they will be in the same Proportion.

N. B. The Instructions I have here given relating to Moldings, I must own will be of little or no Service to a great many Workmen, they being very common in Practice and not very difficult to understand; but as I design this Book for general Use, this Problem may be useful to the younger Sort of Practitioners, and for that Reason I thought proper not to omit it.

PROBLEM XI.

An Architrave being given as E 1st, to draw another in the same Proportion as the Architraves B and D, Fig. 36.

This depends on *Prob. 4. Chap. II.* where you are taught to divide a Line in the same Proportion as another given Line is divided. If you want a lesser than the given one E 2^d, set off your design'd Breadth from the Foot of E, at an Angle you please, and from the Divisions of the given Architrave E, draw parallel Lines, as you see in the Figure, and that will divide the Architrave D, in the same Proportion. And by the same Method you may draw a larger one, as B, *Fig. 37.* and as all the Members are work'd down as far as they are work'd on the Thickness will be increased in the same Proportion, by observing to set off the first Facia the same Thickness as the Bead is to work on, which is given by the parallel Lines, and the Thickness of the Second Facia and the upper Ogee are found by the same Method, or the Thickness may be found by drawing parallel Lines, as the dotted Lines plainly show.

P R O B L E M XII.

*To find the Length of the high Rafter of a Roof
be it bevel or square.*

First, On some convenient Floor, or large Drawing-Board, draw the Out-lines of the Building, according to the Angles, and let B,C,D,E, represent the Out-side of the Plate, *Fig. 38*; then from the square End C, give the Roof its proper Pitch, and draw the Lines O, O, for the common Rafters, and divide the Line C, into as many Parts as the Building is Feet wide, and the last Division, divide into twelve Parts for Inches, and that will be a Scale to measure any Part of the Roof: Then draw the Middle-line represented by the dotted Line A, and draw the dotted Lines *p, p*, the same Distance from the Ends as the Line A, is from the Sides, and from the Points where these Lines intersect, or cross each other, draw the Lines *d, d, d, d*, which will be the Projection of all the Hip Rafters, then take the dotted Line *m*, (which is the Height of the Pitch) and add to each of the Lines *d, d, d, d*, and from thence draw the Lines *b, b, b, b*, as you see in the Figure, and they will be the Hip Rafters of the whole Building. And if you want to find the Length
of

of the short Rafters make a right Angle Triangle, A, *Fig. 39.* and let the Hip *b*, be the Hypotheneuse, the common Rafter C, the opposite Side, and the Base, Half the Breadth of the Building ; which divide according to the Distance you intend for the Rafters, as you see in the Figure A, and apply them to the Scale ; and that will give you the exact Length of any of them, and the Figure will give the Bevel of the upper Ends.

The Bevel or Back of the Hip-Rafter may be found by dividing the Hip with a Line down the Middle, after 'tis cut off to its proper Angle, and from that Line as a Diagonal set off the Angle of each Corner of the Building, and that will give you the Bevel.

N. B. This Problem depends on the Nature of all right-lin'd Figures, in which if the Measure of any one Part be known, it will measure all the Rest.

PROBLEM XIII.

To find the Hip or Angle Rafter of a Roof whose Plan is an Octagon or Hexagon. Fig. 40.

First, Draw the Plan of the Building as large as you can with Conveniency, and from the Middle of one Side, draw the Line O, to the

E
Center,

P R O B L E M XII.

*To find the Length of the high Rafter of a Roof
be it bevel or square.*

First, On some convenient Floor, or large Drawing-Board, draw the Out-lines of the Building, according to the Angles, and let B,C,D,E, represent the Out-side of the Plate, *Fig. 38*; then from the square End C, give the Roof its proper Pitch, and draw the Lines O, O, for the common Rafters, and divide the Line C, into as many Parts as the Building is Feet wide, and the last Division, divide into twelve Parts for Inches, and that will be a Scale to measure any Part of the Roof: Then draw the Middle-line represented by the dotted Line A, and draw the dotted Lines *p, p*, the same Distance from the Ends as the Line A, is from the Sides, and from the Points where these Lines intersect, or cross each other, draw the Lines *d, d, d, d*, which will be the Projection of all the Hip Rafters, then take the dotted Line *m*, (which is the Height of the Pitch) and add to each of the Lines *d, d, d, d*, and from thence draw the Lines *b, b, b, b*, as you see in the Figure, and they will be the Hip Rafters of the whole Building. And if you want to find the Length
of

of the short Rafters make a right Angle Triangle, A, *Fig. 39.* and let the Hip *b*, be the Hypotheneuse, the common Rafter *C*, the opposite Side, and the Base, Half the Breadth of the Building; which divide according to the Distance you intend for the Rafters, as you see in the Figure A, and apply them to the Scale; and that will give you the exact Length of any of them, and the Figure will give the Bevel of the upper Ends.

The Bevel or Back of the Hip-Rafter may be found by dividing the Hip with a Line down the Middle, after 'tis cut off to its proper Angle, and from that Line as a Diagonal set off the Angle of each Corner of the Building, and that will give you the Bevel.

N. B. This Problem depends on the Nature of all right-lin'd Figures, in which if the Measure of any one Part be known, it will measure all the Rest.

PROBLEM XIII.

To find the Hip or Angle Rafter of a Roof whose Plan is an Octagon or Hexagon. Fig. 40.

First, Draw the Plan of the Building as large as you can with Conveniency, and from the Middle of one Side, draw the Line O, to the

E
Center,

Center, and from one of the Angles draw the Line, Z, which will be the Line of Projection of the Angle Rafter, and, O, will be the Line of Projection of the Side Rafter, then take the Line, *a*, the Height you intend for the Roof, and set off at Right Angles, from one End of the Line, O, and Z, and draw the Lines *b*, *d*, to the Center, as you see in the Figure, and they will be the two Rafters; that is, *b*, will be the Side Rafter, and, *d*, the Hip or Angle Rafter. And if you would know the Lengths of the short Rafters; make a Triangle, as, A *Fig. 41.* and let the Base be equal to one Side of the Octagon, Hexagon, &c. and the Sides equal to the Line *d*, and divide the Base, according to the Distance of the Rafters, and draw parallel Lines, as you see in the Figure; then make a Scale of the whole Breadth of the Building, (or any known Part) and that will give you the Length of any Part thereof.

P R O B L E M XIV.

To find the Hip Rafter of an Ogee Roof. Fig. 42.

These Sort of Roofs are very seldom made use of, unless it be for a Summer-House, or some small regular Building, whose Plan is a Square, a Hexagon, or some such even sided Figure.

Suppose,

Suppose, the Plan a Square, as in *Fig. 42*, first set out in the Middle of the Plan, the Square of the Necking you intend to have at the Top, and from thence draw the Lines *a, a*, which are the Lines of Projection of both Rafter, then from either End at right Angles draw the Lines *O, O*, for the Height of the Roof, and they will give you the Length of both the Rafter, which are represented by the dotted Lines, *Z, Z*, and from these you must strike the Ogees of both Rafter, as you see in the Figure ; that is the Side Rafter must be struck from two Centers after the Common Method of striking an Ogee ; but the Angle or Hip Rafter (if you have a Mind to be very exact) must be struck with a Trammel or String ; for as all Ogees are Parts of Cylinders, their Miters will be elliptical ; therefore the Hip Rafter must be consider'd as the Angle Bracket of a Cove, whose Centers may be found, by *Chap. III. Prob. iv.* that is, take the Diameter of the Circle that form'd the Ogee of the Side Rafter, for the Conjugate Diameter, and the Diagonal of that Line squar'd, for the Transverse : and strike them out as the Figure directs, and that will be the Shape of the Hip Rafter exactly.

But as the Difference between an Ogee Hip struck from an Ellipsis, and one struck from a Circle is so very small, they may both be struck out the common Way for any common Business. And as all the Side Rafters, excepting one, will be but Parts of Ogees, they are to be consider'd as if they were whole, and a certain Part cut off at the upper End, as the *Fig. 43.* A will direct, that is to take the shortest Line, *a*, in *Fig. 42*, for the Base of the Triangle A, then take the shortest Line Z, and set off at right Angles from the End of the Line, *a*, and let the longest Line, Z, be the Hypothenuse, as in the Figure, and divide the Line, *a*, according to the Distance of the Rafters, then draw the Line *e*, equal, and parallel to the Line, *a*, and divide it into the same Number of Parts, and draw the Ogees, as you see in the Figure. And where the Miter Ogee, *z*, intersects the other, they must be cut off, and the lower Parts will be the Short Rafters, then make a Scale of any known Part of the Building, as directed *Prob. xii.* of this Chapter) and that will give you the Length of any Part of your Roof. As to the Back, or Bevel, of the Hip Rafter it may be found as before directed.

N.B. There are several other Sorts of Roofs besides those I have here given, which are often

ten used in Building, but as they depend on the same Theory, or at least on some of the foregoing Problems, I think it would be of little Use to give any more Examples here, for if the Theory of those I have already given, are rightly understood, it will naturally lead the Practitioner to find the Rafter, or any other Part of any Roof, let the Shape be what it will.

P R O B L E M XV.

To strike out the Ribs of a Scalene Coue, applied to the Top of a Malt Kiln. Fig. 44.

This Contrivance is very often made use of in the Country to carry off the Smoak, and steam off the Malt when its drying, and erected much after the Manner of the Figure B, the conical Part, A, is fixed on a Center to turn with the *Wind*, over the Figure B, which is a large round Funnel built directly over the Middle of the Malt Kiln. As to the Method of erecting the lower Part, B, I shall leave it to the Practitioner's own Judgment. But as the Top is a Mathematical Figure it must require the Knowledge of Lines to perform it as it should be, therefore I shall give a short Demonstration of the Figure A, by itself. This

Figure if continued quite round, to cover the whole Funnel B, and terminated in a Point at the Top, would be an elliptical Scalene Cone, but there being a Bit wanting at the Top it can only be the Frustrum of such a Cone, that must have a Part left open, as E, to let out the Smoak. The Reason why 'tis elliptical is because the Base, or Bottom, is oblig'd to be a Circle, otherwise it would not turn round, therefore the Ribs ought to be elliptical, and plac'd at right Angles with the Axis, or Middle Line O, which will be the strongest Way and soonest perform'd; for if they are put horizontal, as the dotted Lines, *b, b, b, b*, *Fig. 45.* which is the common Way; they will all be Circles. But then there is a great deal of Trouble to work them bevel, according to the back Line K; therefore to make them elliptical, will save most of that Trouble, and they may be struck out by the following Method.

First, Divide the Cone A, into what Number of Ribs you please, as they are represented by the Lines *u, u, u, u*, then set off the Space you intend to leave for the Smoak, as the Line E, then from the same Base, draw the Frustrum of the upright Cone, D, *Fig. 46.* and divide it into the same Number of Ribs parallel to the Base, then to strike out the first Rib take the

the

the Line n , in the Figure D, for the Transverse Diameter of the Ellipsis, *Fig. 47*. And the Line u , next the Base in *Fig. A*. for the Conjugate Diameter, and proceed to strike out the Ellipsis, as directed *Chap. II*. Then take the second Line u , next the Base, for the Conjugate Diameter of the Second Rib, and diminish the Transverse in the same Proportion, that is let the Center Pins of your Trammel remain the same Distance one from the other, as before, and strike the Ellipsis a, a , *Fig. 47*. which will be the Second Rib; and by the same Method strike out the Rest, as the *Fig. D*, will direct, and as to that Part of the Ellipsis, which will be for Use, they may be discover'd by cutting off as much of every Conjugate Diameter of the Ellipsis, as the Line E, in *Fig. 44*, cuts off from each Rib, and as the dotted Lines *Fig. 47* directs.

P R O B L E M XVI.

To strike out a Sash and Frame, with a circular Head and Front, for a circular Building, with Directions how to work the same. Fig. 48.

These Sorts of Windows are not very often made use of in Building, but where the Founder doth not value the Expence, and if they
are

are well introduc'd, they must certainly appear with a noble Grandeur, and render a Building very magnificent. It must be allowed, that such a Piece of Work is very difficult to perform, and must require a good Hand, that hath been us'd to Compass Work to undertake it. But was I to perform the same, I should proceed in the following Manner.

First, To find the Center of the circular Part of the Building, and draw the Plan of the Sash Frame, B, which is represented by the Sill D, then make three Molds, one to the Inside of the Sash-Frame, another for the Inside of the lower Sash, and the third for the Inside of the upper Sash ; then glew up a Board by the first Mold, as large as the whole Frame, and there on the Convex Side draw out the whole Sash and Frame, as may be suppos'd like the Figure 49, G. But here it is to be observ'd, that in drawing out the circular Head of the Sash and Frame, if the Center was a Semicircle that turn'd the Arch in the Building, it will not be so on the Compass-Board you draw on, for if you endeavour with a Pair of Compasses, from one Point, to strike a Circle on a Cylinder, it will be an Ellipsis in Plano, and from the same Reason an Ellipsis may be so proportion'd, as to be a Circle when taken off the
Cylind-

Cylinder, which may easily be done, by covering it with Paper and taking it off when struck out, and laying it on the Plane. From hence 'tis plain, that the Lines for the Head of the Window G, when drawn on a Compass-Board that is Part of a Cylinder cannot be struck from one Center, but must be elliptical, whose Diameters may be found by Girting over the Compass Board with a Line, as far as the Width of the Sash Frames, and that will be the Transverse Diameter represented by the Lines, O, O, in the Figure G, that Line must be laid down on a plain Board, then take the Line, *a*, in the Figure, *n* Fig. 50. for the Conjugate, and place it at right Angles from the Middle, and by *Prob. vii. Chap. III.* find out the Center to strike the Ellipsis with a String, and set off those two Centers on the Line O, O, in Figure G, and there fix two Nails and with a String strike out the Arch *m*, and by setting off proper Margins, the whole Head of the Sash and Frame, may be struck out by the same Center. This being done, compleat the whole Window by drawing every Part in its full Proportion.

Then begin to work the Head of the Sash Frame, by fitting of solid Pieces (that are thick enough and wide enough for the Head of the
Frame,

Frame, Beads included) so as to make a Joint to the Compass-Board, or Mould, you work on, according as the Lines direct; and from the under Side so fitted, gauge them to their proper Thickness, and mortise and tenent them together (as you see in the Figure) according to the Number of Pieces, observing to let the solid Part come low enough to receive the Pully-Pieces and Frames, which may be let in Flush, and nail'd to the same. The Head being thus prepar'd and pin'd together, lay it down on the Board where it was first fitted, and fix a Piece of Wood of the same Thickness over the Centers at *a*, and transfer those Centers before given to the Top of the Piece so fix'd, and let them be a small Matter wider asunder, by Reason this upper Side of the Sash Frame must be wider than the lower Side, to answer the Splay of the Pully-pieces, which ought to point to the Center of the Building, according to the first Figure D. The Head of the Frame being work'd according to the given Arch; gauge off the Beads; rebate the Space between (which is the Thickness of the two Sashes,) and stick the Beads, and the Head will fit the Arch propos'd.

The other Part of the Frame being not very difficult to perform, needs no Direction here
therefore

therefore the next Thing I should do, would be, to take the second Mould (which is the Inside of the lower Sash) and fix the Compass Board to the same, by setting it a little wider with two Braces underneath, untill it become flat enough to fit the Mold. It being thus fix'd begin the lower Sash, which may be bent (if the Curve is not too quick) in three Parts, after the common Way of performing such Work the upper Sash may be work'd after the same Manner, (when the Compass Board is set to the third Mould as before directed) excepting the Semicircle Part, whose Curves being of a Compound Nature cannot be bent in Thicknesses, therefore I should chuse to bed the Rail and Spandrels after the Manner as before directed for the Head of the Sash Frame.



C H A P. V.

Of the Nature and Properties of Arches, shewing what Shape are most durable, and capable of supporting the greatest Weight, with some Remarks on the intended New Bridge at Westminster.

BY the Word *Arch*, we are taught to conceive the Idea of some regular Curve, or crooked Line, as the Line, A, *Fig. 51.* which when applied to Practice in Building is always put with the Convex Side uppermost in order to support some Weight, as the *Fig. D.* But without the Butments, *e, e*; (if it was in Parts as Building requires) it would not support itself, for the Action of Gravity pressing upon it, would soon tumble it down: And was it a flexible or malleable Body, would soon reduce it to a streight Line.

From hence 'tis plain, that the Strength of all Arches depends upon the Butments, and that
Depen-

Dependency is in Proportion to the Height they rise from the Chord Line of their respective Arches, which Line is represented by the Line A, in *Fig. D.*

The Truth of this will very plainly appear by setting up two Sticks (or Pieces of Wood in the Shape of Leavers) one against the other on a Plain Board, in the Nature of a Pediment, as the Lines *o, o*, *Fig. 52.* and *a, a*, *Fig. 53.* in the Arches, A and B. I say, the Pediment *o, o*, requires a greater Weight, or resisting Power, to be plac'd at the Foot *e, e*, to keep it from falling, than the Pediment *a, a*, therefore the Arch B, will consequently support a greater Weight than the Arch A, if their Butments are equal. The Reason of it is the Lines *a, a*, are nearer a Perpendicular than the Lines *o, o*, for if those before mention'd Pieces of Wood, were plac'd perpendicular one against the other, with a Hinge at the Top, and Wheels put in the Bottom for the Sake of Experiment to take off the Friction; they would in that Position, want no Butment to keep them together at Bottom, but if they are a small Space asunder at the Bottom, they will want a Butment to keep them in that Position, otherwise they will run one from the other, and the further they recede from each other, the

greater must the resisting Power, or Butment be, to keep them from falling.

From what hath been said it appears, that Gravity acts on those two Leavers, according as they are elevated or depress'd; and if so it must be in some Proportion; which Proportion may very nearly be determin'd by the following Figure G, *Fig. 55.* whose Theory depends on that of the Steel Yard; which for the better Understanding of what is to follow, I shall endeavour to explain, by the next *Fig. 54. E.* Let the Line *c* and *o*, represent the Beam, and *o*, the Center of a Pair of Steel-Yards, and suppose two Weights, as, *n*, and *r*, were to be hung at equal Distance from the Center, *O*, and the other Part of the Beam cut off, they would then hang in Equilibrium, that is, *n* and *r*, would be equal. But if the other Part of the Beam was to be added, and the Weight *n*, was carried on the Beam, as far as the Figure 10, and suppose the Weight was but one Pound each, then I say that the Weight *r*, must have Nine Pounds added to it to make it ballance the Weight *n*, when remov'd so far from the Center. But here 'tis necessary to observe, that in making those Instruments, the Weight that is occasion'd by the Length of the Beam is always accounted

ed for before they begin to divide, and 'tis very easy to discover what Weight did belong to a Pair of Steeliards, supposing it to be lost) by taking the Distance between the Centers of the Hooks, that is between *O*, and *r*, and apply it to the proper Edge, and the Division there will tell you what the Weight should be, for it is that Distance multiplied into the whole Length, as you may see in the Figure. But here in this present Case the Beam is only imaginary, for it is the Distance from the Center, that Occasions all those different Gravitations, for if we suppose the Circle, *a, b, c, d*, to be a Wheel, and, *o*, its Center, and a Weight of one Pound to be fix'd at its Periphery at *b*, and the Wheel to be turn'd round, the Weight when it is got to *e*, it will be 3 Pounds, and at *Z* 5; and the Gravitation of such a Weight will increase in the same Proportion, as if it was carried along the Beam, *e*, as you may see by the Divisions. By this useful Instrument may also be discover'd the Power of the Leaver from a Perpendicular to a horizontal Position, and may very justly be call'd a Scale to measure all mechanick Powers that act from Centers, and notwithstanding our present Subject be two Leavers set up one against another, yet I believe the next Figure will make it appear

very plain, that they also depend on the same Theory, and are subject to the same Laws of Gravitation. For as those two Leavers, *a, a*, in *Fig. 55 G.* support one another at the Top, and prevent their falling or acting like Leavers; yet, I conceive that Gravity will act on the Bottoms (when the Friction is taken off by Wheels) in the same Proportion, as if they were turn'd End for End, according to the Left Hand Side of the Figure *G*, when turn'd upside down, that is to put the confin'd End downwards, and let the upper Ends fall one from the other. I say in the Fall of such a Leaver, the Gravitation would be increas'd in the same Proportion as is there set down. For if the Leaver *a*, by falling from the perpendicular Line *G*, should have gain'd a Force of one Pound, it would at *e* have gain'd three Pounds at *z* 5, and so on in Proportion, as was gain'd by the Weight at the Periphery of the Wheel in *Fig. E*, until it becomes horizontal. In the same Proportion I conceive Gravity to act at the Bottom of the two Leavers *a, a*, that is, if at *a*, they should want a Butment of one Pound at each Foot to keep them in their Position; at *e* they would want three, and at *z* 5, and so on in the same Proportion as they are set down in the Right Hand Side

Side of the Figure G, until they become so far extended as to lie level on the Plane they moved on ; from what hath been demonstrated from *Fig. G*, it is plain that Gravity acts on Pediments, according as their Sides are elevated or depress'd : And if so it must certainly act on all Arches in the same Proportion, as their inscrib'd Pediments are to one another in Respect to their Height. And from hence may be discover'd how much Weight one Arch will bear more than another, that is the same Width, and hath the same Butments to support it. That is, if the lower Arch, in *Fig. D. 56.* will bear 500 Pound Weight, the Arch *a*, will bear 600, and the Arch *b* 700, and so on according to what Height you rise ; may the Weight be increas'd, which will always be in Proportion as the Sides of the inscrib'd Pediments are to one another, when their Chord Lines, or Widths, are the same, as you see in the Figure.

Notwithstanding I have given this Method to shew how much one Arch will bear more than another of the same Width and Butments, yet I do not pretend to know, how much Weight any Arch will bear, for there is no Arch that I know of, that can be said to bear all the Weight that is built perpendicular over

it ; because that Part hath Communication with Rest of the Building, and cemented to it in such a Manner that takes off a considerable Part of the Weight that would otherwise press upon it, if that Communication was destroy'd. And I may venture to say, that it is from this Reason, that Arches sometimes become so loose that their Key Stones are almost ready to drop, for Want of a sufficient Weight, to keep their Parts together.

From this Observation it is plain, that all Arches want a Weight proportionable to the Height they rise to keep their Parts firm in the Situation they are first plac'd, for it is very reasonable to think that the Arches of *London* Bridge would not have remain'd so intire to this Day, if it was not for the Weight of Houses that are erected thereon, which must certainly prevent those frequent Shocks and Shakings that it must otherwise have suffer'd by loaded Carts and Carrs, and other Vehicles of Burden that daily pass and repass thereon.

But whether the intended New Bridge is to have any such, I know not, or whether the Ground Rents of such Houses would be equivalent to the Expence of making the Bridge so much the wider, I will not pretend

to determine altho' I believe, that the Revenues arising from thence would be very considerable.

But to proceed, to make some Observations on the Shape of Arches, in Respect to their Duration.

I think the most common Sort that are to be found amongst our Modern Buildings are either Semicircles, Segments, or Semi-Ellipsis, which I must own have an agreeable Effect on the Eye, because they are Part of Regular Figures, and make a good Appearance in a Building, if they are well proportion'd, and well introduc'd, but this is not always observed by our Modern Builders, for I have often seen a Passage of three Foot wide with a Semicircle Arch, and a Gateway of ten, with an elliptical one, whose Height from the Springing hath not exceeded twenty Inches; such a one cannot be supposed to be of any long Duration, without very strong Abutments, unless the Weight be discharged by a concealed Breastsummer, or very little laid thereon. In such Cases, Ornament is consulted more than Strength for the Arch of three Foot being a Semicircle will bear above ten Times more Weight than the elliptical one of ten Feet, with the same Butments by Reason of its Flatness, and double Centers,

Centers, which must render it very weak and unfit to support a great Burthen. I mean such Ellipsis whose transverse Diameter is plac'd horizontal, as B, *Fig. 57.* but if you take an Ellipsis the other Way for an Arch, and let the Conjugate Diameter be horizontal, as A, then it will become altogether as strong, and may very justly be esteem'd the best Sort to support a great Burthen, excepting those formed by the Catenarian, which I shall endeavour to prove (before I leave this Subject) the strongest of all and most durable. But for the Truth of what I have asserted in respect to the elliptical Arches A and B, I must refer the Reader to a very easy and familiar Experiment, which is to take an Egg (whose Shape is near enough for the Purpose) and try whether it will not bear a great deal more Weight on the Ends than it will on the Sides before it burst, such an Experiment seems to me to put this Matter out of the Reach of Contradiction, and will justify the Theory that I have hitherto endeavour'd to explain. Namely, that all Arches will bear a Weight proportionable to the Height they rise from their Springing, if their Chord Lines, or Openings, are the same, let the Shape be what it will altho' it must be allow'd that some Sort of Shape will bear more Weight than

than another of the same Height and Butments, for if the elliptical Arch B was a Segment of a Circle of the same Height, it would add much to its Strength by Reason that Curve would be more uniform and approach nearer to a Catenarian than it was before in that flat elliptical Form, for it is my Opinion, that the Strength of all Arches would be increased the nearer they approach that firm Arch of Nature, for so I must call it, by Reason it is form'd by Action of Gravity, which must be allow'd to be a natural Cause.

This Curve, or Arch, may be discover'd by suspending a Chain, or flexible Line (that is not very light) from two horizontal Points, or Nails, as *o, o*, in *Fig. 58 D*, the Curve, or Arch, that such a Line, or Chain, will form, is call'd a Catenarian, represented by the Line *a*. This Line, as I before observ'd, is form'd by the Action of Gravity, which acts on all Bodies, according to their Density, or Quantity, of Matter they contain, if their Form and Shape are the same; therefore, if Gravity by its Action on a slack Line, or Chain, forms the Arch *a*, it is very plain, that if it were turn'd upside down it would form the Arch *K*, which consequently must resist that Action in the same Proportion, as the other gave Way, that is *K* would

would become an Arch of equal Strength in all its Parts, and for that Reason must certainly be the best Shape for any Arch that is to bear a great Burthen.

But, as the Properties of the Catenarian Arches are so far conceal'd that it would be very difficult to assign any Centers that would strike the same, for if they are very flat they appear like Segments of large Circles, but if you endeavour to form a Semicircle by letting the Line drop half its Opening, it will then appear elliptical, and as you drop it lower it seems to approach the Hyperbola, so that the distant Appearances it makes in these different Stations must render it very difficult to find out proper Centers to strike them out.

But for those that have Occasion to apply them to Practice may observe the following Method, and may answer the Purpose very well, if it be carefully observ'd, that it is to take such a Line (as beforemention'd) and rub it with Chalk, or Charcoal, until it be fit to leave an Impression then on some flat Plain or Board (that is large enough for the Use) fix in two Nails horizontally, according to the Width of your Arch, and from thence let the Line fall as far below the horizontal Line *a*, in *Fig. G. 59.* as you would have the Arch to rise
above

above it, then carefully press the Line hard enough to leave the Impression, and that will be the Arch required as n , then move the Nails from o to K , according to the Margin you intend to show in the Front, and from them let fall the Arch m , and that will limit the Border, or Margin, which may be divided and Mould made to fit the Curve in the same Manner, as if the Arch was in any other Form, as you may see in the Figure, which in Practice must be turn'd upside down; but, as I observed before, that the lower the Line was let fall the nearer it approach'd an Hyperbola, therefore it cannot be expected that the Lines n , and m , will be parallel or appear concentrick like Arches struck from the same Center, but for those that should think it appeared disagreeable for the Margin of an Arch to be wider at Top, as *Fig. G.* may easily prevent it by making the Moulds parallel to the inward Arch n , which would be a Matter of Indifference in respect to its Strength.

But notwithstanding all those distant Appearances before-mention'd that are made by the Catenarian Line, yet I cannot help thinking, but that they are all of the Hyperbola Kind; for as the Hyperbola is that Section of a Cone cut any where when parallel to its Axis, I say
it

it is no hard Matter to imagine a Cone large enough that will admit of the flattest, as well as the highest Arches to be cut off by such a Section ; now, I believe it will appear from what I have already said on this Subject, that Catenarian Arches are the best Shape for Duration, and for that Reason the most proper Form for the New Bridge on the River *Thames*, if it be built with Stone. But be it as it will, I think the Foundation ought to be of Stone, as far as High Water Mark, and considering the Depth of the River must require some Contrivance to lay the lower Stones, and fix a Basement in Water firm enough to support so heavy a Weight that must consequently depend thereon.

As to the Laying the Foundation, which is commonly built in Coffer-Dams, and which are carried to their proper Places in the River, and the Foundation there begun, and carried on in those, observing as the Foundation sinks to make good their Out-Work, to keep out the Water, and so work on untill the Pier is got above the Surface of the Water. This Method is practic'd abroad, where Buildings of this Nature are more common, and may do very well where the Piers are small: But I cannot apprehend how such a Method can be

be practic'd with a good Effect in the River *Thames*, where the Tide is constantly ebbing and flowing, and the Piers very large and heavy; neither am I able to conceive how a Foundation of that Nature can be well laid and secured where the Workmen have not firm Ground to work on, but altho' I cannot foresee the good Effect of such a Proceeding. This Method may be practicable, and may (for ought I know) be the only one intended to execute the Design of the Bridge. But if it be so determin'd, I hope it will be no Affront to those Gentlemen concern'd, if I offer another that (according to my Notion of Things of this Nature,) will do as well, if not better, if it be not thought too expensive, which is to circumscribe the Place in the River where the Piers are to stand with the Piles and Planks duff-tailed and grooved together and sharpened and well shod with Iron fit to drive into the Bottom of the River in the Form of the Plan B, *Fig. 60.* the Length of those Piles and Planks must be determin'd by the Depth of the Water, allowing for that Part that is to go into the Foundation. The Substance of the Piles ought to be substantial. The Thickness of the Plank about 6 or 8 Inches, and the Piles to be drove in about four Foot asunder, and

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the

the Planks between, and so on till the whole Range be compleated. Such a Range of Piles and Planks may be too weak to resist the external Pressure of the Water, and if so, they may easily be strengthened by driving in other Piles along the Outside, about four or five Foot from some of the others that belong to the Range, and brace them with diagonal Braces, and that will be a Security against the external Water and prevent it, pushing it down when the internal Water is all pump'd out. And if the Grooves (which ought not to go stiff) were dress'd with Grease, or Tar, or some such Matter, it will make them drive the better, and be a Means to prevent their Leaking, not as it can be supposed that such a Fence will be without any. But I cannot apprehend, that there will be any Leaks so large, or numerous, but they may be discharged by Chain Pumps, and the Place kept dry enough for the Workman to lay the Foundation, as well as if there was no River to interrupt them; This Method seems to me to be more agreeable to the Nature of the Design, than the former one before mention'd; but as I can give no Precedent of any Proceedings of this Nature, I must leave the Publick to judge of the Effect. At the Place where the Bridge is to cross the River,

Care

Care ought to be taken, that it be where the Stream hath a direct Course, and the Bridge to be built at right Angles to the Stream, otherwise it will render the Passage for Boats and Barges more dangerous and difficult to pass and repass than if the Stream run parallel to the Sides of the Arches.

This I must own is a plain Observation, but very necessary to be observ'd by those that are intrusted to set out the Place where the Bridge is to cross the River.

Here I intended to have finish'd this Subject; but seeing two Pamphlets publish'd, the one being a Design for the Bridge, the other a Reply to Mr. *James's Review*, by which I am inform'd, that not only one Mr. *Langly*, but several ingenious Gentlemen have some Time ago publish'd their Designs and Calculations relating to this new intended Bridge, which had I known before (it is very probable) would have prevented my saying any Thing about it. But as their Views in publishing seem different from mine, and I have unwarily enter'd upon this Subject, I shall venture to go on with it a little further, not as I would willingly enter into that Controversy that hath been so warmly disputed amongst those that would have their Schemes perform'd. But what I intend

only to make some few Remarks on what I have seen, which will render the Subject on Arches the more compleat, and may chance to give this Performance a better Taste to the Publick.

Mr. *Langley*, in the Beginning of his Design for the Bridge, hath taken a great deal of Pains to estimate the Fall of Water that will be occasion'd by a Bridge being built over the River *Thames*, either at the *Horse Ferry*, or at *New Palace Yard*, and in his Reply to Mr. *James* hath bestow'd several Pages in the Vindication thereof.

But, supposing this new intended Bridge should occasion a Fall of Water that will be an Inch or two more or less than Mr. *Langley* would have it to be, or that it will be High Water between the two Bridges before it is above the New One, seems to me to be a Matter of no Consequence, since it must be allow'd by all that know any Thing of the Matter, that the New Bridge will not occasion any material Difference in the Height of the Tides in general, but that they will flow to the same Height as usual.

I think such Niceties as those may be consider'd but as Trifles in Respect to the principal Design, which is to erect a Bridge over
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the River in the most expeditious Manner and to be both convenient and durable, how far these Designs and Direction propos'd by Mr. *Langley* and others are likely to answer the End, I shall not venture to enquire.

As my chief Design is to demonstrate the Nature and Property of Arches. I shall begin my Remarks on these design'd by Mr. *Langly*, which being of the Catenarian Kind (as I have before observ'd) are the strongest of all other, and for that Reason, the most proper to apply to a New Bridge over the River of *Thames* if they are well proportion'd, and had Mr. *Langly* but design'd them lower or laid a greater Weight (or Thickness) on the Crowns of those he hath there given, I should have thought it more consistent with the Nature and Property of such Arches whose Height is more than half their Opening, for it hath before (in p. 49.) been demonstrated that all Arches will bear a Weight (on their Crowns) proportionable to the Height they rise, if their Abutments are the same, and if they will bear it, it is plain they want it from the following Observation that may be made of a common Tub or drinking Vessel which may very justly be said to have the same Properties of an Arch, for the Staves may

be consider'd as so many Stones whose Joint Point to one common Center, and the Hoops that circumscribe them as their Weight or Pressure then I think it cannot be deny'd by any Person (of common Understanding) that the tighter those Hoopes are drove on round such a Vessel the more compact it must keep the Staves and the stronger the Vessel will be for such a Weight or Pressure therefore it appears to me, that Weight on an Arch will have the same Effect as a Hoop hath on a Tub if the Weight be well proportion'd.

But in order to give my Opinion in this Affair the Actions of Gravity on solid Bodies ought to be understood and the Shape of the Arch well consider'd before a Man can form any Judgment about the Weight it will carry, or on what Part to bestow it to the best Advantage, therefore for the better understanding what is to follow on this Subject. I shall venture to lay down the following Theorems.

- I. When any Weight presses on the Sides or Haunches of an Arch the Weight on the Crown must be consider'd as an Abutment to that Weight on the Haunches and in Proportion to the Height they rise from the Cord Lines of their respective Segments, will the

the Weight on the Crown be required.

II. And as the Weight on the Crown is an Abutment to the Weight on the Haunches so is the Weight on the Haunches an Abutment to the Weight on the Crown.

III. And as the Weight on the the Haunches wants to reduce the Curvature thereof to a straight Line, contrary to that, doth the Weight on the Crown want to make it rise higher or push it out at Foot if there is no Abutment plac'd there to prevent it, and both would produce that Effect if it was not for a Counter-Ballance of Power as will be best explain'd by the following Figure.

As I have p.53. propos'd a Method in order to discover how much Weight one Arch will bear more than another that hath the same Extent and with the same Abutments, I shall here consider what Effect the Weight on the Haunches hath on Arches of different Shape, this Method is built on the same Theory as the Former and to save the Reader the Trouble of turning back (as the Figure is nearly the same) I shall explain it thus:

If

If the Segment Arch, a, e, e , fig. 61. will bear 5 Hundred (or a Tun) Weight the Semi-circle, a, b, c , will bear 6 Hundred with the same Abutments, and the Cartinarian a, d, c , will bear the Weight in respect to the Abutments below but if they are both consider'd as having no Weight on their Haunches, the Cartinarian must be the strongest, by reason of the Curvature of its Haunches are nearer a right Line than those of the Semi-circle for was there as much Weight laid on the Crown of the Catenarian Arch as it would just bear the same Weight if apply'd to the Semi-circle would occasion it to burst out and fall down, which plainly sheweth that the Semi-circle wants a greater on its Haunches to Counter-Ballance the same Weight on the Crown, and how much more Weight is required on the Haunches of the Semi-circle to counter-balance the same Weight on the Crowns of both may be (nearly) discover'd by the same Method, for by drawing the Cord Line o , will cut off one Haunch of both which may be consider'd as whole Arches and the Difference of Weight be discover'd in the same Manner for if the Haunch of the Catenarian requires nine hundred Weights the Semi-circle will require Ten, to enable it to support the same Weight on the Crown as the Catenarian

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rian and the Haunch of the Segment *a, e, c*, is likewise subject to the same Rule, and requires but seven, by Reason the Haunch is not so much elevated which gives the Weight a greater Gravitation.

In like Manner may the Difference of Weight be discover'd in any two Arches, which will always be in Proportion, as the Chord Lines of their respective Segments are to one another, or in Proportion, as the Sides of their inscrib'd Pediments are to one another, which implies the same Thing as may be seen by the Figure.

In P. 50 and 51, the Reader may find I have there explain'd the Nature and Property of the Steel-Yard, and in the next Page have made use of its Power, to discover what Power a Leaver gains by falling from a Perpendicular to a horizontal Position, and likewise to prove that all Arches want an Abutment proportionable to the Height they rise, and as that answer'd the Purpose so far as to appear to me a Demonstration, I shall introduce the same Power, and by it examine Mr. Price's Middle Arch, in the Manner following, *Fig. 62.*

Let A, B, C represent the Arch propos'd, now if we suppose, that the half Arch B, C, was in one Stone, and its Weight 28 Tun and
a half,

a half, and that it was by some Power to be lifted upon its Pier w , until it come to its Center of Gravity, which may be suppos'd to be at d , then it is very plain, that the Pier must bear all its Weight, and if from thence it was to be let down to a horizontal Position, as at x , and a Support put under the End, as at o , the Support o , would bear 14 Tun and one Quarter, and the Pier w would bear the same Weight, and was it from thence to be lifted up to its proper Place at B , and there supported, then will the Pier w , bear $20\frac{1}{4}$ Ton, and the Support at B , bear $8\frac{1}{4}$ Ton, for the End B , being elevated, the Support o , is releas'd of 6 Ton Weight, which consequently must be added to the Pier; for as this half Arch is suppos'd to be in one Stone, it may be consider'd as a Leaver, and be subject to the same Laws of Gravitation, as hath before been demonstrated, and may be explain'd by this Figure.

This Method seems to me to give some Insight, whereby the real Weight of the Abutments may be discover'd; for if the Support o , was taken away, and the other half Arch A, B , was set up against it in its proper Position, that must certainly throw the whole Weight of both on their respective Piers, but as A, B ,
is

is set at the same Angle, as B, C, they would thrust each other down, if there was not an Abutment plac'd at A and C, to prevent it. Now, if we consider, that before A, B was set up against B, C, the Support *c*, supported 8 Tons and a Quarter; therefore the Thrust of A, B must be equal to that Weight, if there was no Friction at *c*, and if so, it appears very plain to me, that a Weight of 8 Tons and a Quarter, plac'd at A, and at C, will be a sufficient Abutment for the Arch, A, B, C; for as such a Weight is a counter Ballance to the Thrust there will be the Friction of A, B, C, on the Piers for a further Security, which, considering the great Weight of A, B, C, may, perhaps, be equal to two Ton more, but this must be refer'd to Experiment.

And, if the Arch A, B, C was to be consider'd in Parts, as the Half A, B, the Weight or Pressure, would still be the same, for by drawing parallel Lines from the Joints to the Chord Line plainly sheweth how the Weight is diminish'd, as appears by the Figure.

By what I have endeavour'd to demonstrate, it appears very plain, that the Center which is to support the Arch, A, B, C, will be releas'd of 12 Ton Weight, in the Thickness of the

the whole Breadth, which is suppos'd to be 40 Feet, and the Number being multiplied by 12, the Produce is 480, which being reduct-ed out of 2320 (which is suppos'd to be the Weight of the Whole) the Remainder is 1840, which will be nearly the Weight (when that of the Key-stone is deducted out) that will lie on the Center before it can be reliev'd by the Key-stone. How much of the Spandrel's Weight will press on the Arch is very difficult to discover, because it hath a Communication with the upper Pier, or Breast-work, which takes off a great deal of the Pressure, but was that Communication to be destroy'd, and it was to be consider'd as one Stone, and to have no Friction on the Arch, it could then be only said to lean on the Arch, and what Weight that Leaning is may in some Measure be discover'd by the same Rule as the former; that is to draw a Line, as *d*, (in the 62d Figure) in such a Manner, that if the Spandrel was lifted up on its lower Point until that Line become perpendicular, it would then be the Center of Gravity, and if the Line *d*, was continued to cut the Arch *P*, and from thence let fall a Perpendicular to the Chord Line, which if divided according to the Weight of the whole Spandrel, it will give the Weight that

that will press on the Arch if the Line *d*, be so drawn as the Quantity of Matter on both Sides are equal, which ought to be regarded in the half Arch, B, C, as well as in this present Case.

I should not have applied this Power to the Spandrel had it not been to have shew'd the Extensiveness of this Method in Respect to Arches as well as to other mechanical Operations, not as I will pretend that this Method will discover exactly the Weight, or Pressure, of any Arch, but I believe it will be near enough to let a Man know what he is about when he either designs or erects one.

But, as the Spandrel will be work'd up with the Upright of the Pier and cramp'd and cemented together, and the Joints dispos'd of in such a Manner as will take off most of its Pressure, unless it be those Stones near the Crown, which have no Occasion to be laid on until the Key-stone is fix'd, and I cannot help thinking, but that it may be fix'd before the Spandrels are begun, provided it have a Bearing on the Center, especially in those Sort of Arches that are of the Catenarian Kind, whose Haunches, I dare say, would suffer no Disturbance, if the Key-stone had a Bearing on the Center.

If this Arch will admit of being work'd up after this Manner there is no Occasion to allow any Weight for the Spandrel, so that then there will be no more Weight to account for (that will lie on the Center) than that of the Arch itself, which, according to this Way of Demonstration, will be no more than 840 Tons, which is several Tons less than some Men have imagin'd will lay thereon.

As this Center must be forty or more Feet long, I do not see any Reason to double it, it being able to support the Arch, if the Weight of it was as much more; for if the great Length be consider'd in respect to the Weight, the Weight must appear but inconsiderable in regard to the Weight that such a Center may be made to bear, and if the Centers are made with Judgment, and allow'd a firm Foundation, or Bearing, at the Springing it is unknown what a Weight such a Center will bear.

From what hath hitherto been endeavour'd to be demonstrated, in Respect to Arches it appears to me, that their Strength doth not so much depend on their Shape, as the Weight they bear, being well adapted thereto; for altho' it must be granted, that Catenarian Arches (if consider'd as independant of any Weight

but

but their own) are the strongest of all other, yet if the Weight on their Crowns is not proportionable to the Height they rise; they may be said to be weaker than a Semicircle, or Arches, of any other Form, if their Weight and Abutments are well proportion'd, and if I may be allow'd to give my Opinion on those Arches, design'd by Mr. *Langly*, Mr. *Price* and Mr. *Hawkmoor*, (which are all I have seen that are design'd for the Bridge) I must give the Preference to that design'd by Mr. *Hawkmoor*, for notwithstanding the Shape is a Semicircle, the Weight seems the best proportion'd and the Nature of the finishing the best adapted to the Situation; but, however that be, it cannot be denied, but that the Arches in either of the Designs (if well executed) would support a Bridge over the *Thames*, but then I think it would have been to a better Effect if they had been allow'd a greater Thickness of Building over their Crowns, which according to my Way of Thinking they all seem to want, especially those design'd by Mr. *Langly*, which by Reason of its Shape are best able to support it, and had he but allow'd a greater Thickness between the Crown of his Arches and the Paving of the Bridge, it would consequently have added a greater Weight, which, in all

Probability, would have prevented that unequal Pressure occasion'd by the Declination of the Bridge from having a bad Effect on the Arches, which in order to prevent hath lessened the Weight on the Haunches by cylindrical Vacuities proportionable to the Difference of their Pressure, which is monstrously absurd.

But this I conceive Mr. *Langly* hath introduc'd through Ignorance; for had he consider'd, that the Weight on the Haunches is not so great as it appears to be, and that what is, may be consider'd as an Abutment, he could never have imagin'd, that the Unequalness of their Pressure would occasion their ~~Proportion~~ rupture and falling down, if the next adjoining should chance to be remov'd by either Time, or Accident.

I say, if he had laid a greater Weight on the Crowns of those Arches he design'd for the Bridge, and omitted those cylindrical Vacuities he hath there introduc'd, his Arches would then have appear'd to me more capable of Duration, and this he might easily have perform'd; for if the Surface of the Bridge would not admit of being carried any higher the Arches might have been made lower, and by that Means have gain'd a proper
Thicknefs

Thickness between their Crowns and the Paving of the Bridge.

This Alteration, I must own, would occasion a greater Thrust from the Crowns to the Abutments below, but as the Upright of one of his Piers taken from the Springing of his Middle Arch, consider'd as one Foot thick, contains above 112 Ton Weight, it would be more than sufficient to counter-balance the Weight or Thrust from the Crown, and be able to support any of his Arches independent of each other, for carrying the Building a convenient Height above the Arches, not only loads the Arch, but the Pier also, which must be consider'd as an Abutment to the Weight laid on the Crown, for it is not the Extent of an Abutment, but the Solidity that ought to be consider'd as most capable to resist any Force, or Power, that wants to remove it; therefore as the Abutment increases in Proportion to the Weight laid on the Crown, I cannot see how an Arch can be well over-loaded if their Abutments are good, and there is no more Weight laid on than the Foundation will bear, which, I must own, ought to be consider'd.

But to strengthen this Argument, I think, the Arches of *London Bridge* may be consider'd

as a very good Precedent to shew what Weight Arches will bear, for as the Distance between the Crowns of those Arches and the Paving of that Bridge, by far exceeds any that is design'd for the new One, and if the Materials are the same the Weight must exceed in the same Proportion, and add to that the Load of Houses, and then consider the Length of Time that those Arches have supported that Weight. I say, if these Things are consider'd, I cannot see any Occasion for our modern Designers to be so fearful of overloading these Arches, and omitting a Weight or Thickness where it is most wanted.

This I shall endeavour to make appear by the following Comparison, which, notwithstanding it being a low one, may chance to be more convincing than any Argument I can make use of, that is, (if sma'l Things may be compar'd to great) I don't know any Thing that appears so much like a Bridge supported by Arches, as a long Board cut in Pidgeon-holes. Now I think it cannot be deny'd by any Man that hath any Notion of Building, that the nearer those Holes or little Arches are cut to the upper Edge of the Board, the weaker such a Board will be, and consequently the more unfit to support any Weight that should be roll'd over it. Therefore, if this Comparison be just, it must appear
 very

very plain that the Strength of all Bridges (in respect to heavy Burdens passing over them) must depend on the Thickness or Strength of Materials that are work'd over their Crowns.

For if that thickness of Materials be considered as a Quantity of Matter at rest, that is to receive a lesser Quantity in Motion, it must certainly be necessary to so proportion those Quantities of Matter, that the Lesser will give no Disturbance to the Greater, for it cannot be deny'd but that a lesser Quantity of Matter in Motion may disturb a greater Quantity that is at rest, therefore it's very reasonable to think that heavy Burdens passing over any Bridge, whose Quantity of Matter or Materials on the Crown is not sufficient to resist the Motion of the Burden passing over, must in Time suffer Damage; for its well known that so small a Weight or Quantity of Matter as a Coach and Pair, by moving with a swift Velocity (over pav'd Stones) doth very often affect the Houses of several Streets in *London*, by causing a very sensible Tremulation in the Buildings thereof.

I say, this may chance to be of an ill Consequence to any publick Bridge supported by Arches that hath not a sufficient Thickness of Materials laid on their Crowns that is able to resist the Jolts and Surges of any Burden that may chance
to

to pass over it without suffering any Disturbance thereby, and it is from this Consideration that I have before observ'd (in *p. 54*) that the Weight of Houses erected on *London-Bridge* hath very much contributed to its Preservation, by preventing those frequent Strokes and Shakings that it must otherwise have felt, if such a Weight had not been laid thereon, and if Weight hath been a Benefit to the Old Bridge it must consequently have the same Effect on a New One.

As to laying the Foundation of the Piers in Coffers, or Floats, I have before (in *p. 60.*) shew'd my Dislike, and have there given a Method that seem'd to me more practicable, but since my reading two Pamphlets, and finding that several ingenious Men have thought it worth their Consideration, it hath induced me to think more closely on the Subject, therefore I shall venture to propose another which will be less expensive, and to a better Effect.

In my former Method, I propos'd Piles and Planks to be dovetail'd, grov'd together, and sharpen'd at the lower Ends and shod with Iron, in order to drive into the Foundation round the Plan of the Piers to keep out the Water until the Foundation was laid, and carry'd on above High Water Mark, which I believe would have answer'd the End propos'd, but as considering the
Accu-

Accuracy of the Workmanship that will be requir'd in such a Performance, and the Time it will take up to make so many Grooves in a Dovetail Form, and also the Difficulty that will attend the getting of them asunder in order to make them drive again, hath occasion'd my altering of my first Design to the Method following.

This is instead of the before-mention'd Planks and Piles that was propos'd to be dovetail'd together and drove seperately into the Foundation, I here propose they should be made into Flood-gates which will have no Occasion to be grov'd but only join'd together and made in two Thicknesses after the common Manner of making such Gates, as is shew'd in *fig. 63.* only the lower End of the long Planks must be sharpen'd, and the Sides or Edges so sharpen'd should be bevel'd off in such a Manner as to leave an Edge in the Middle that when they are well shod with Iron they may the better cut their Way into the Foundation, the Piles must be grov'd to receive the Gates, and to be done in such a Form as will circumscribe the Plan of the Pier, observing to leave Room for Men to Work.

The Distance of the Piles to be about four Feet which will terminate the Width of the Gates which are to be drove into the Foundation
between :

between every two Piles, which for the better Conveniency of driving must have a Capfill tenant on to the upper End to raise the Weight whose Thickness ought to be the same as the Capfill and the Shape like that I have given at the Top of the Gate, and to slide in Groves to give it a proper Direction, after the common Method of driving of Piles.

Such a Range of Gates and Piles (as I have observ'd before) by Reason of their great Length will want to be strengthen'd to make them able to resist the external Pressure of Water which (undoubtedly) will be very great. Therefore in this Case, as in the former, there must be other Piles drove in (without-side the Range) 4 or 5 Foot distance from every second or third Pile belonging to the whole Range, and brac'd there-to Diagonal Ways as near to the Bottom as the lowest Water will admit, which will add a great deal of Strength to the whole Range and prevent the Weight of Water from pushing it down.

Such a Method if the Materials are good the Work well perform'd and carefully executed is very likely to keep out the external Water, when the internal is all laved or pump'd out, for I cannot conceive that the Leakes will let in more Water than a Chain Pump or two will be able to discharge, by Reason all those Leaks that
will

will happen above Low Water Mark may be stop'd from without, and those that happen below may be stopp'd from within as the internal Water sinks, therefore, I cannot see any Room to doubt of the Foundation being laid dry, or at least dry enough for Workmen to lay the Foundation of any of the Piers, and to work with the same Safety, as if the whole Current of the River was turn'd into some other Channel.

I say, this Method is the more likely to answer the End propos'd, by Reason it is nearly the same that hath been so long practic'd by Millwrights to dam up large Heads of Water for the Use of Mills in Rivers which they generally turn into some other Channel, and by that Means can come at the Bottom of the River to lay in a Ground Sill for the Gates to shut, which are commonly made to shut so close as to let no Water pass by when the Gates are shut.

But to compensate for such a Sill which cannot be laid with any Certainty in the River *Thames*, I have propos'd the Gates to be made in such a Manner as will drive into the Bottom of the River, which appears to me to be a better Security to prevent their Blowing at Bottom, than any Ground Sill be it never so well bedded to the River's Bottom, and as the sharpen'd
Ends

Ends of such a Gate taken together will contain but a little more Solidity than the sharpen'd End of a single Pile, that is one Foot Square, it's very likely to want but a little more Power to drive it in, and considering the Gate will be in Parts, it may, perhaps, require less, but this I refer to Experiment.

As to the Nature of the Foundation or Bottom of the River where the Bridge is to cross over, I must own, that I am unacquainted therewith, but it hath been observ'd that it consists of two Stratum, the one Clay and the other Gravel; and in order to suit both, they have propos'd two Sorts of Coffers, or Floats, for the laying the Foundations of the Piers, but the Method that must be made use of to make the Materials of one serve again for another is what is conceal'd, but whether they are conceal'd for the Reasons there given, or from some other Motives, I will not pretend to determine.

But however that be, I believe it will appear from the Nature and Form of those Materials I have propos'd for that Purpose, that after they have perform'd their Duty to the first Piers they will admit of being drawn out and drove in again (to the same Effect) for the Second, and if there is but one Pier to be carried on at the same Time it is not impossible for one Set of Gates

Gates and Piles to serve for the whole Bridge, for be the Stratum at the Bottom, either Clay or Gravel, if the Gates and Piles be well shod with Iron, there is no Fear, but they will make their Way into the Foundation.

And if the Bottom of the River consists of two such Stratum as Clay and Gravel, it is reasonable to think that the Gravel is the lowermost, and must appear in the Channel, and if so, according the River's Section, the Stratum of Clay cannot be of any great Thickness, but may be clear'd off from the Gravel at a less Expence, and to a better Effect, than to drive in a great Number of Piles, and after that to be at the Expence of Oak Planks, in order to gain a Foundation, when perhaps the Sinking of two or three Foot may save that Expence, and have a better Foundation, than can be expected from any Timber whatsoever, for unless it can be demonstrated, that Timber is as durable as Stone, (I think) it ought to be rejected as unfit to support any Stone Building, especially one that is design'd for the Use of Ages to come.

I am not insensible, that Oak-Timber will last (if buried in Earth or Water) many Years longer than if it was expos'd to the different Mediums of our Atmosphere, which is conti-

nually shrinking and swelling all such porous Bodies, that in Time destroys the Cohesion of their Parts, and occasions them to molder away and become reduc'd into their first Principles. But, notwithstanding this Difference, it cannot be denied, but that Stone is more durable than Timber; therefore it would be very improper to put the Weak to support the Strong, and for those who have a Mind to see the Effect of such a Foundation may go no farther than the New Church at *Westminster*, where they may soon be convinc'd by the several Fractures that are visible in that Building, that Piles and Planks (which is Part of that Foundation) is an improper Basement to support a Stone Bridge over the River *Thames*.

But to give the greater Credit to such a Proposal, the Author hath endeavour'd to persuade us, that *London Bridge* hath no other: But this by way of Supposition, and I do not see why any Body else may not (with as good Reason on their Side) suppose the contrary, for if the great Weight of that Bridge be consider'd, and the many Years it hath been supported by the Foundation, there is but little Reason to believe it to consist of Piles and Planks, but rather of some good hard Stone well bedded on a Stratum of firm Gravel that hath been able to resist so great a Pressure for so many Years.

Neither can I see any good Reason for Mr. *James* to suspect the River's Bottom of being insecure, and not able to support a Stone Bridge; for it is well known, that where the
Foundation

Foundation of Roads are become insecure, and have a proper Descent to carry off a Current of Water when let in upon them. I say, such Roads (if they are not a Clay) will become more secure, for Water being let in upon them, and seldom want any other Repair.

Therefore it is reasonable to believe, that the Bottom of the River *Thames* cannot be the worse for so large a Current of Water passing over it, but the better, and if the same Stratum are to be met with, at the *Wooll Staple*, or *New Palace Yard*, or at the *Horse Ferry*, as are at *London-Bridge*, there is no Room to doubt of their supporting so great a Weight.

I might have enlarg'd my Observations on what others have publish'd relating to the Bridge. But as I have already carried this Performance to a greater Length than I first design'd it, and the Time seems to be so near at Hand that the Bridge must be begun; I shall forbear to make any further Remarks thereon; but only observe, by way of Caution to those it may concern that good Nature hath always been esteem'd a very amiable Quality in an Author, and where that is wanting the Force of his Arguments are very often lost, for when a Man is angry his Reason is generally suspended, and he seeth Things through a false Medium, and what he hath to say against an Adversary at such a Time ought not so much to be rely'd on, as if it had been the Result of a cool and deliberate Consideration; therefore, I think, there ought to be some Aliowance in Cases of this Nature, and
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before

before we censure (too rashly) the Mistakes of others, we ought to consider those of our own.

I say, such a Reflection if it did not make us over-look the Mistakes of others, it ought to at least to direct one of our Eyes towards their Merit; for it is but reasonable, for every Man that pretends to have any Merit of his own, to have some Regard to the Merit of others, and if a Man is not insolently ignorant he ought to merit our Compassion rather than Contempt; for my own Part I am sensible of this Imperfection in our Nature, and should be very unwilling to affirm any Thing as positive that will not bear Demonstration, especially any Thing of so precarious a Nature as the laying a Foundation for a Bridge over the River *Thames*; which nothing but Experiment can justify to be right, for notwithstanding what I have propos'd, for that Undertaking, may appear to me to be practicable; it may appear otherwise to those of a more discerning Judgment, who (very likely) may propose better of their own, which if they do, it will give me no Manner of Concern, because I have no Expectation of any Fee or Reward whatsoever; therefore I shall have more willingly offered what I have said (in respect to the Bridge) to the Perusal of the Publick, hoping they will be so good-natured as to excuse the Want of fine Language, or some other Defects that may (very likely) be found in this Performance, which I shall now conclude.



F I N I S.

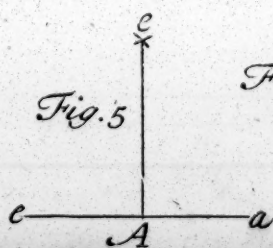
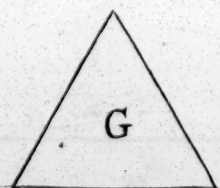
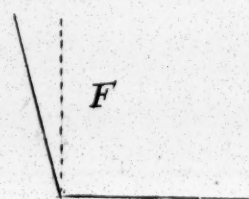
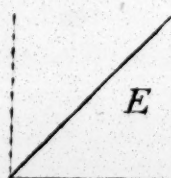
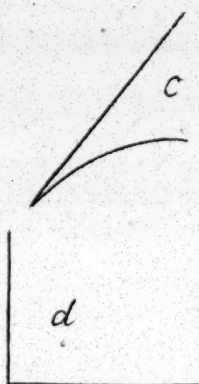
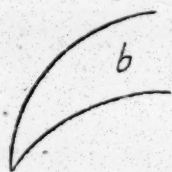
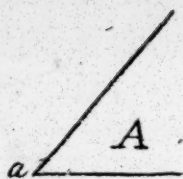


Fig. 1

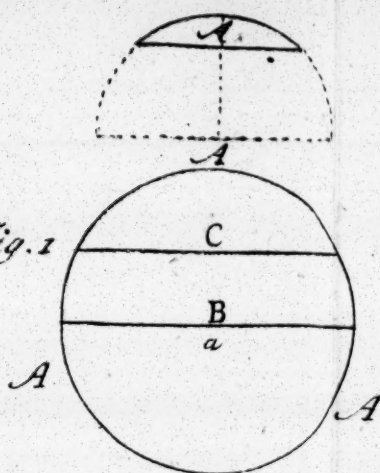


Fig. 2

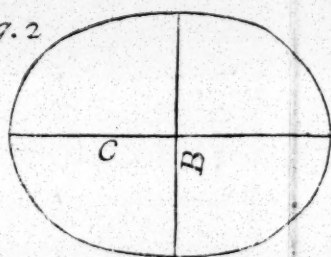


Fig. 3

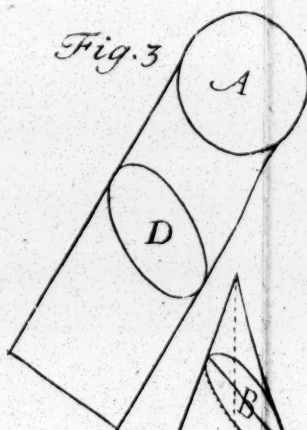


Fig. 4

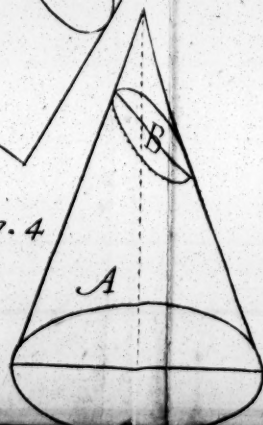


Fig. 5

D

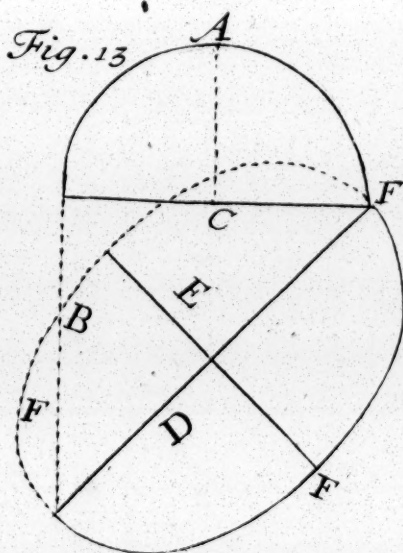
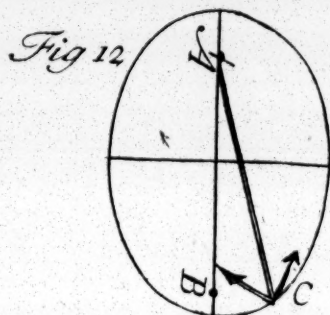
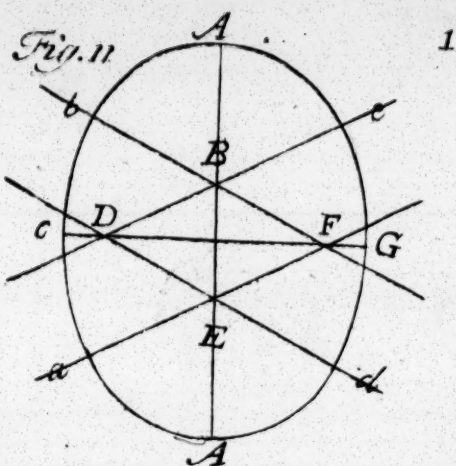
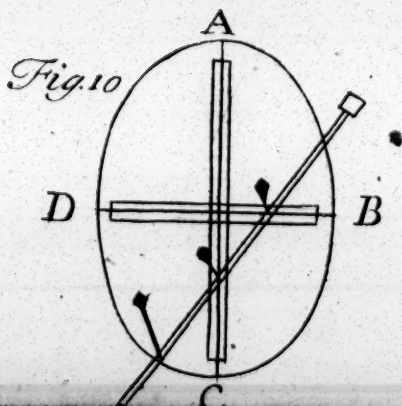
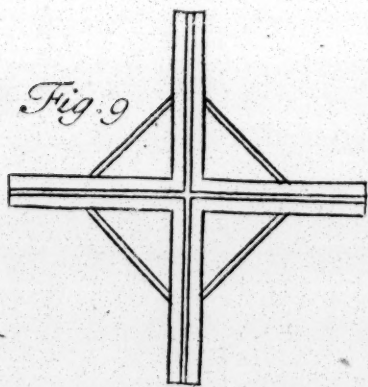
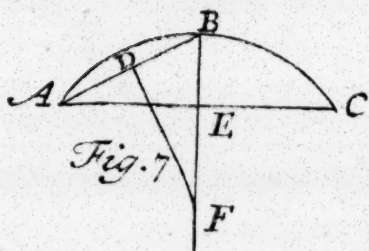
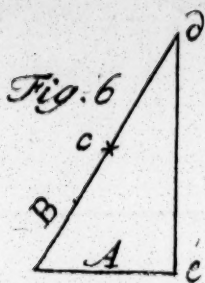


Fig. 14

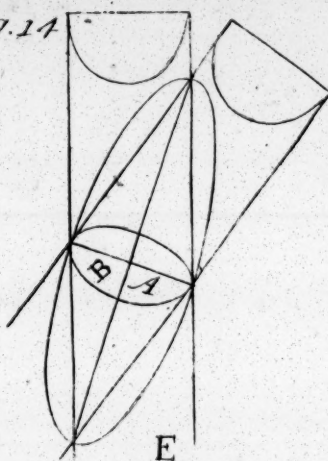


Fig. 15

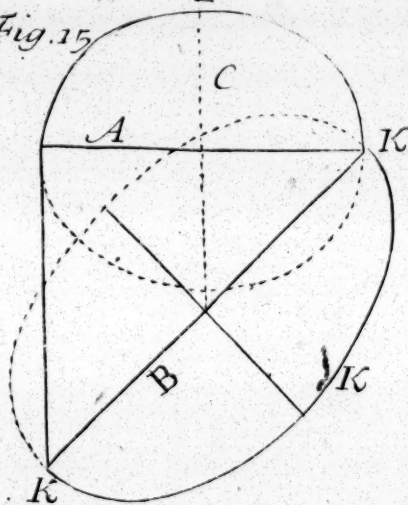


Fig. 16

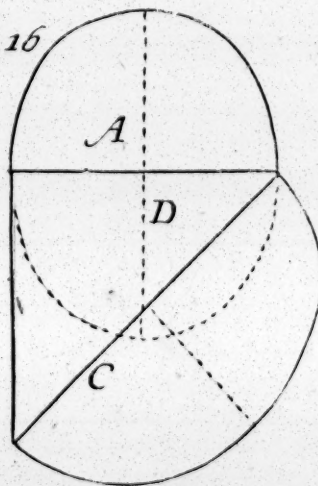


Fig. 17

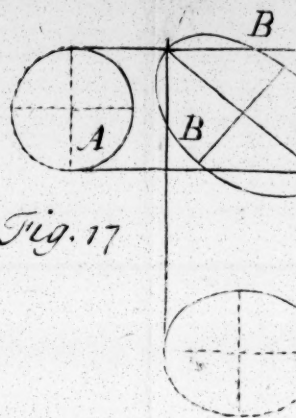


Fig. 18

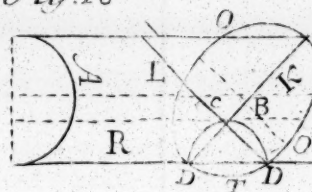


Fig. 19

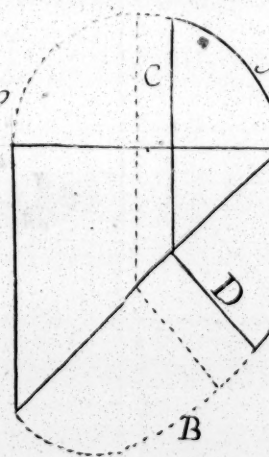


Fig. 20

